AVIATION ELECTRONICS TECHNICIAN 3 & 2

NAVY
TRAINING
COURSES

AVIATION ELECTRONICS TECHNICIAN

3 & 2

Prepared by

U.S. BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10317

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1956

PREFACE

This book was written to serve as an aid for enlisted men of the U. S. Navy and the U. S. Naval Reserve who are preparing for advancement to the rates of Aviation Electronics Technician 3 and 2. Combined with the necessary practical experience and a thorough study of the basic Navy Training Courses, the information contained in this volume will assist the reader in preparing for the examinations for advancement in rating. The courses which contain the material upon which the present course is based are represented by the texts, *Basic Electricity*, NavPers 10086, and *Basic Electronics*, NavPers 10087. These texts should be studied before beginning the course *Aviation Electronics Technician 3 and 2.*

The book provides information concerning aviation electrical systems, typical airborne radar installations, test equipment, general procedures and methods useful in maintenance and repair, communications systems, electronic navigation aids, radar bombing attachments, and airborne electronic countermeasures equipment.

As one of the Navy Training Courses, this book was prepared by the U. S. Navy Training Publications Center, Memphis, Tennessee, and the Training Division of the Bureau of Naval Personnel. Credit is also given to the Aviation Electronics Technician School, Memphis, Tennessee, for supplying the end-of-chapter questions which thoroughly review the materials contained in each chapter.

CONTENTS

CONTENTS—Continued

CHAPTER 10

CHAPTER 11

APPENDIX I

APPENDIX II

APPENDIX III

APPENDIX IV

READING LIST

NAVY TRAINING COURSES

Basic Electricity, NavPers 10086
Basic Electronics, NavPers 10087
Introduction to Radio Equipment, NavPers 10172–A
Advanced Work in Aircraft Radio, NavPers 10314
Electricity, NavPers 10622–B
Naval Electronics, Part I, NavPers 10808–A
Physics for Electronics Technicians, NavPers 10095
Essentials of Mathematics for Electronics Technicians, NavPers 10093–A
Advanced Mathematics for Electronics Technicians, NavPers 10094
Basic Hand Tool Skills, NavPers 10085
Blueprint Reading, NavPers 10077
Aviation Supply, NavPers 10394–B

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to the AT rating is as follows:

Number	Title
	Self-Teaching
EM 415	*Radio for Beginners*
EM 416	*Electricity for Beginners*
MA 887	*Intermediate Radio*
EM 962	*Principles and Practice of Radio Servicing*
	Correspondence
J 310	*Radio for Beginners*
CA 887	*Intermediate Radio*

* "Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

AVIATION
ELECTRONICS TECHNICIAN 3 & 2

CHAPTER 1

AIRCRAFT ELECTRIC POWER SYSTEMS

In order for the technician to keep electrical and electronics equipment in operation, it is necessary that he have an understanding of the electrical power system of the aircraft in which he is flying. He must have sufficient knowledge of the system to enable him to recognize and meet the electrical emergencies that may occur during flight. If he is to fulfill his important duties as a member of his squadron and aircrew, he must have a fundamental knowledge of the means by which aircraft electrical power is produced, regulated, controlled, and distributed. With this basic understanding he will be able to recognize readily and to analyze any emergencies that require immediate action, and either to correct the cause or replace the defective circuit by redistribution of power. In so doing, he can make maximum use of the equipment for which he is responsible.

Many naval aircraft contain two electrical systems: a primary system, which supplies direct current at 24 to 28 volts; and an alternating-current system which supplies both 115-volt, single-phase power and three-phase power at either 115 or 200 volts. External power receptacles are located on the aircraft and provide a means of attaching external sources of power to the aircraft for engine starting and ground operation of the electrical and electronic equipment. In addition to this, many of the larger aircraft are also equipped with an auxiliary power unit (APU) to provide power in emergencies, while the aircraft is on the ground, or during water operations. The auxiliary power unit consists of an independently operated gasoline engine

which drives a generator: the generator supplies the power to the electrical system.

These sources of power are connected through switches and control equipment to a MAIN BUS system. The main bus consists of a copper bar or bars, fitted with screw connections for the attachment of feeder lines. The connections are enclosed in metal junction boxes. In small planes, the main bus connects the power through fuses or other protective devices to the electrical equipment. In larger aircraft, the main bus connects the sources of power through a system of feeder lines to a number of individual buses and distribution panels located at various stations within the aircraft.

Usually an essential, or emergency, bus system is provided to connect power to the flight instruments in the event of power failure of the main bus. A few circuits are not connected through either the essential or the main bus, but are connected directly to the battery and have power available to them at all times. These consist of submersion actuator circuits, the IFF destructor, and those lights and devices necessary for the initial boarding of the aircraft.

Figure 1–1 is a diagram of an electrical system which is typical of those used in large aircraft.

The alternating-current generator (labeled 1) is connected through a voltage regulator to an a-c power switch. This switch selects either the plane's a-c generator or external a-c power for the distribution panel. From the distribution or control panel, 115-volt, three-phase and single-phase power is distributed to individual buses and control panels in various parts of the aircraft. At these panels power is further distributed to the equipment through fuses or circuit breakers.

The direct-current generators (labeled 2, 3, and 4 in fig. 1–1) supply approximately 27.5 volts, direct current, to the main d-c bus through the switches shown. The aircraft battery is also connected to this bus through a junction box. In addition to the d-c generators and the battery, an external d-c power receptacle is provided which can connect external

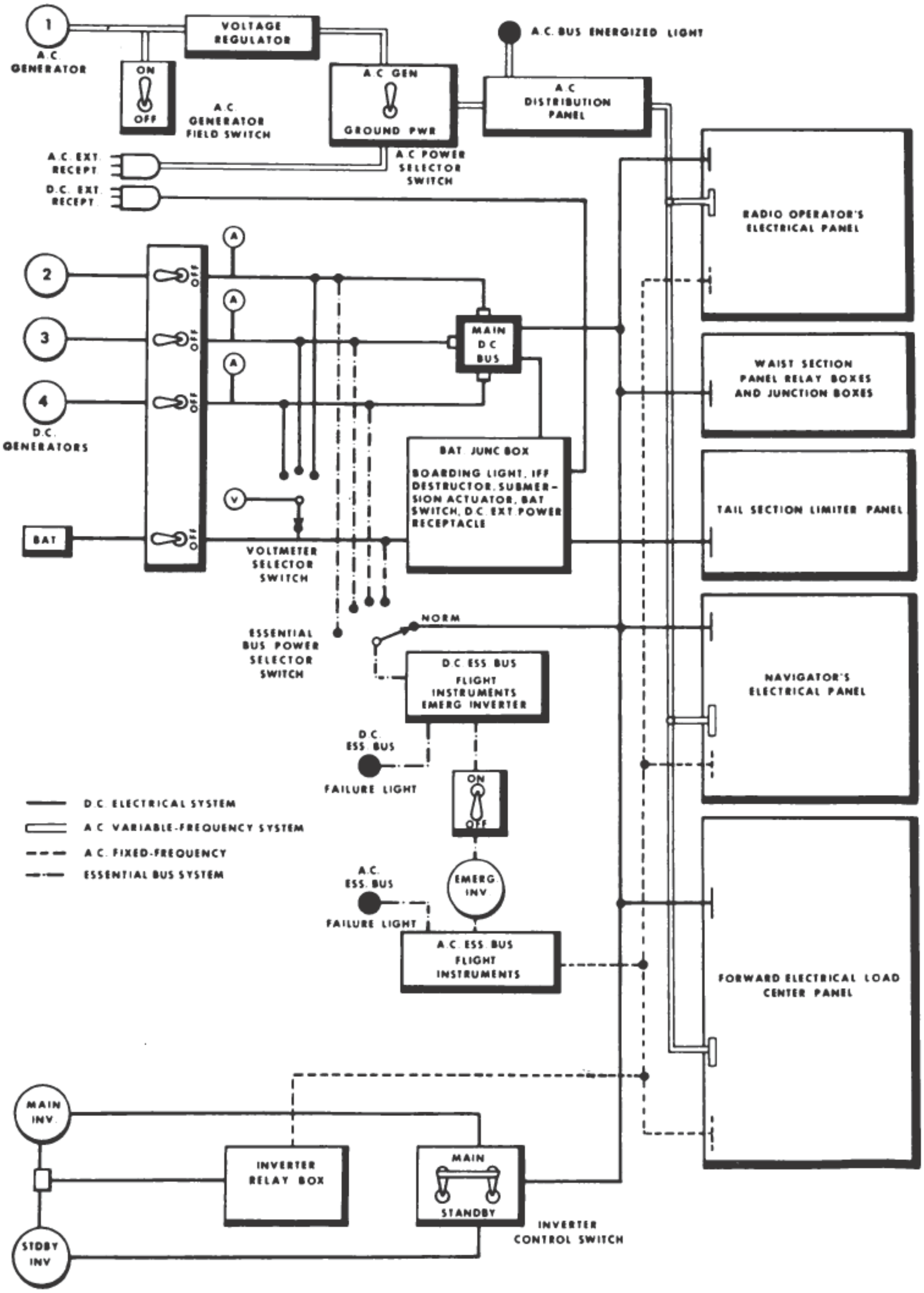


Figure 1–1.—Block diagram of typical aircraft electrical system.

d-c power to the main d-c bus. A voltmeter, selector switch, and three ammeters are included in the system. These meters permit a constant check on the output of the d-c generators and the voltage of the battery.

A d-c essential bus is shown in the approximate center of the figure. Through its power selector switch it can be attached to the main bus, to the battery, or to any one of the three d-c generators. The d-c power selected is then distributed to those instruments and electrical equipment which are necessary to maintain flight of the aircraft, and also to the emergency inverter. (An INVERTER is a machine which converts direct current to alternating current.) The emergency inverter supplies a-c power to the alternating-current essential bus when failures of the main and standby inverters occur.

An additional a-c supply is shown at the lower part of the figure. The main, or the standby inverter, through a selector switch and relay box, supplies fixed-frequency, 400-cycle alternating current to the individual distribution panels in the aircraft and to the a-c essential bus. Normally, the main inverter is operated continuously and supplies fixed-frequency, a-c power; the standby inverter is used only when the main inverter fails. In this way an alternate source of power is maintained, and the possibility of both inverters failing during flight is less than if the operating time were divided equally.

DIRECT-CURRENT SYSTEMS

The primary system, usually a 24- to 28-volt, single wire, direct-current system, consists of one or more of each of these principal components: A battery, an engine-driven generator, a voltage regulator, and a reverse-current relay (differential-type relay). In most installations the positive lead of the d-c system is insulated and the metal structure of the aircraft is used as a negative (ground) lead.

Figure 1–2 is a basic diagram of a single-generator d-c system which shows the connection of the main system components. The resistor, R_{load} represents a typical value of resistance which might be presented by the equipment deriving power from the system.

The battery supply usually consists of one or more 24-volt storage batteries and is used as the source of electrical

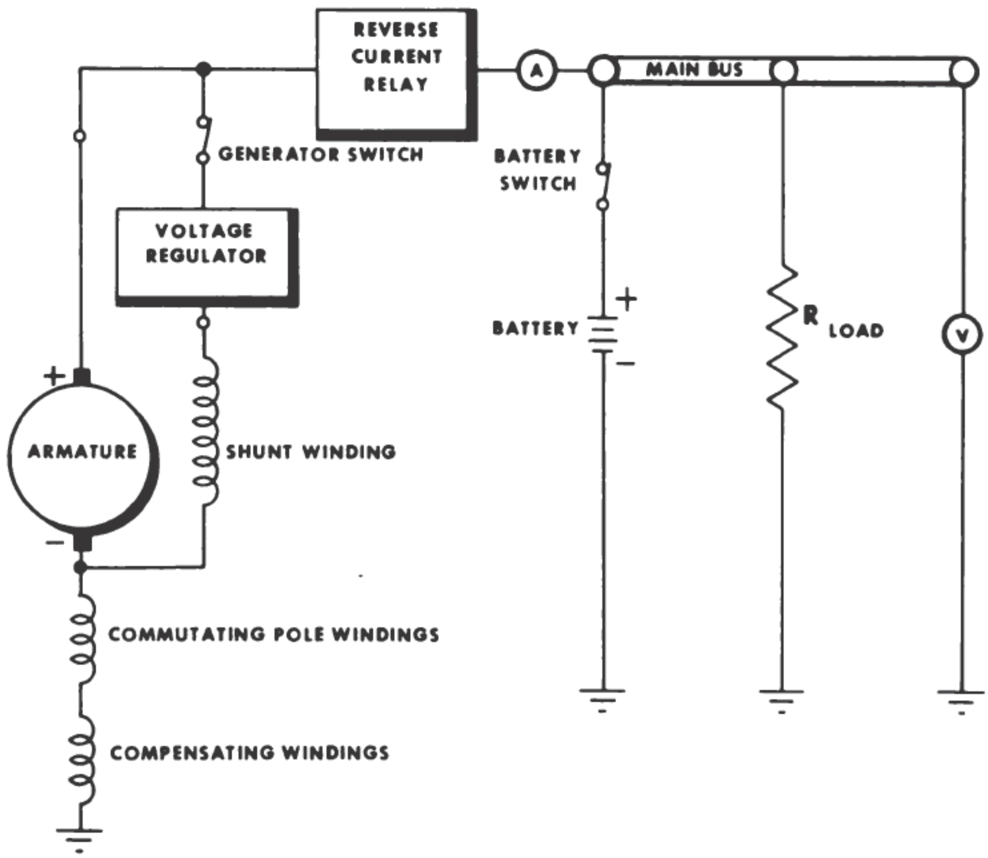


Figure 1–2.—Basic diagram of single-generator d-c supply.

energy during low engine speeds, for engine starting when no other source is available, or in case of generator failure. Aircraft batteries are of small capacity to save weight; consequently, the battery should not be used as a power source for test equipment, or for engine starting when other sources such as auxiliary power units are available. The battery is connected to the main bus system of the aircraft through a master battery switch. This switch provides a means of disconnecting the battery from the aircraft electrical system while the plane is idle or while repairs are being made to the system, and of de-energizing the electrical system when a crash is imminent. These switches are usually of the solenoid-type and are located on the pilot's control panel in the aircraft.

In most aircraft, two or more engine-driven d-c generators are installed which furnish the normal d-c requirements

during flight and keep the battery charged. These generators are usually shunt machines; that is, the magnetic field winding is connected in parallel with the armature. Most generators also employ commutating pole windings and compensating windings which are connected in series with the armature and load as shown in figure 1–2. The commutating poles minimize sparking of the brushes and the compensating windings oppose field distortion due to armature reaction. The magnetic field produced by these windings does not add to that produced by the shunt field winding used for producing the output voltage.

The continuous rating of d-c generators is in terms of speed range, volts, and amperes. The rated speed of a generator is the speed range within which the machine produces the rated output voltage. The speed ranges of most aircraft generators are from 2,000 to 4,000 r. p. m. and from 4,000 to 8,000 r. p. m. Others are designed to operate up to 9,000 r. p. m. with high field currents and forced air cooling, which results in reduced weight and size. The armature of the generator is coupled to the aircraft engine by a splined shaft which engages a gear assembly. The gear ratio is step-up so that the generator armature turns faster than the engine.

The electrical output of the generator is connected to the main bus system through a reverse-current relay, shown in figure 1–2, which automatically connects the generator to the bus when the output voltage reaches a preset value, and disconnects the generator when the output voltage drops below this value. Since the output voltage of the generator is dependent on the armature speed, the engine to which the generator is coupled must reach a certain minimum speed before the relay will close and connect the generator to the bus.

The d-c generators used in aircraft are usually designed for an output of 27.5 volts. The output voltage of the generator is determined by the armature speed, the electrical load, and the strength of the field current. Therefore, fluctuation in any of these three factors will result in varia-

tion of the unregulated output voltage of the generator. Because a constant generator voltage is required, a voltage regulator is provided to maintain a constant output voltage with varying load and speed within the normal rating of the generator. The voltage regulator accomplishes this by automatically varying the resistance in the generator field circuit, thereby varying the field current. The voltage regulator usually employed in aircraft generator systems is the carbon pile type.

The action of the voltage regulator can be understood from the circuit illustrated in figure 1–3. Basically, a voltage regulator consists of a variable resistor and a solenoid. In the figure, the variable resistor symbol represents the carbon pile. The variable resistor of the regulator is connected in series with the shunt field of the generator, and is controlled by the solenoid which is connected across the generator output circuit.

With the generator in operation and the field switch

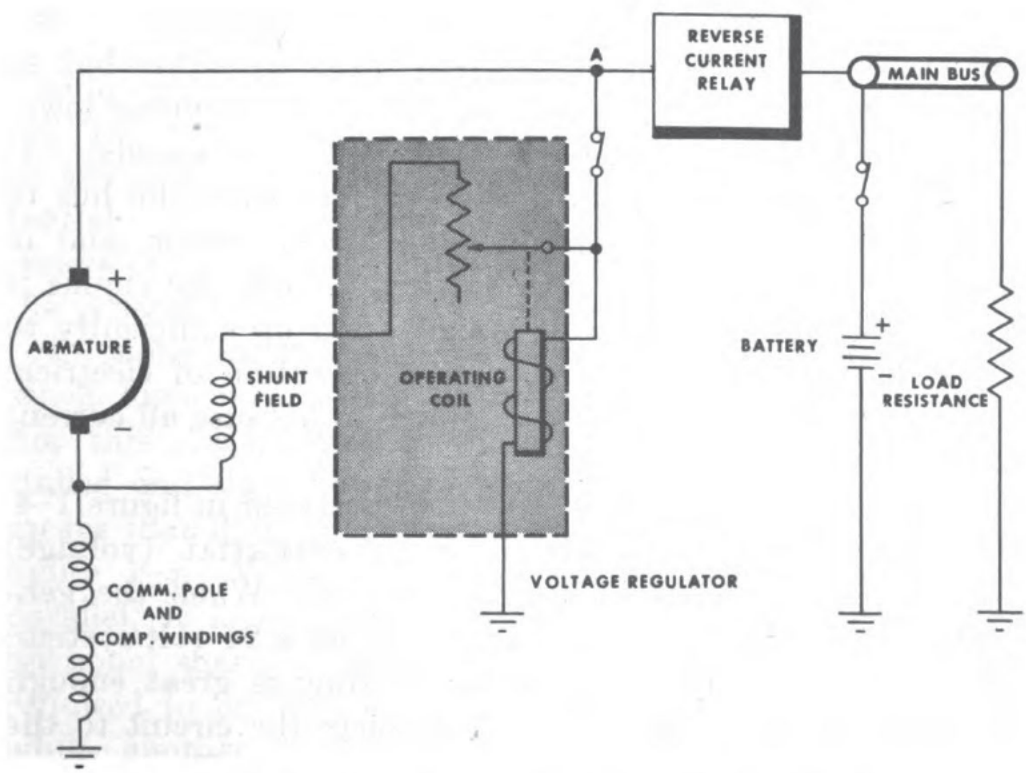


Figure 1–3.—Basic diagram of voltage regulator circuit.

closed, the solenoid, which controls the position of the moving arm of the variable resistor, is connected across the generator output (point A to ground). An increase in generator output at A will cause more current to flow through the solenoid coil. This increased current causes the core and the moving arm to be drawn downward, increasing the amount of resistance which is in series with the shunt field of the generator. Increasing the resistance of the field circuit causes a decrease in the field current and field excitation. This results in a corresponding decrease in generator output voltage.

When the generator voltage decreases, the regulator decreases the resistance of the field circuit. Decreasing the field resistance causes an increase in field current and excitation and a consequent increase in the output voltage. Through this action the output voltage is maintained nearly constant.

The REVERSE CURRENT RELAY, or cutout, connects the generator to the electrical system when the generator voltage is above the normal bus voltage (about 26.5 volts for a 24-volt system). It disconnects the generator from the electrical system when a reverse current flows from the bus to the generator due to the generator voltage becoming lower than the battery voltage (at lower generator speeds). It thus prevents a very high flow of current from the bus to the generator which might damage the generator, and in any case would discharge the battery. When the engine is idling the generator voltage cannot build up sufficiently to close the reverse current relay, and operation of electrical equipment should be held to a minimum because all current is drawn from the battery.

A simple reverse current relay is illustrated in figure 1–4. This relay employs two windings: a POTENTIAL (voltage) winding, and a SERIES (current) winding. When the generator reaches approximately 26.5 volts for a 24-volt system, the current through the potential winding is great enough to close the relay points which complete the circuit to the load, through the series winding of the relay. The magnetism of the series winding aids the potential winding in keep-

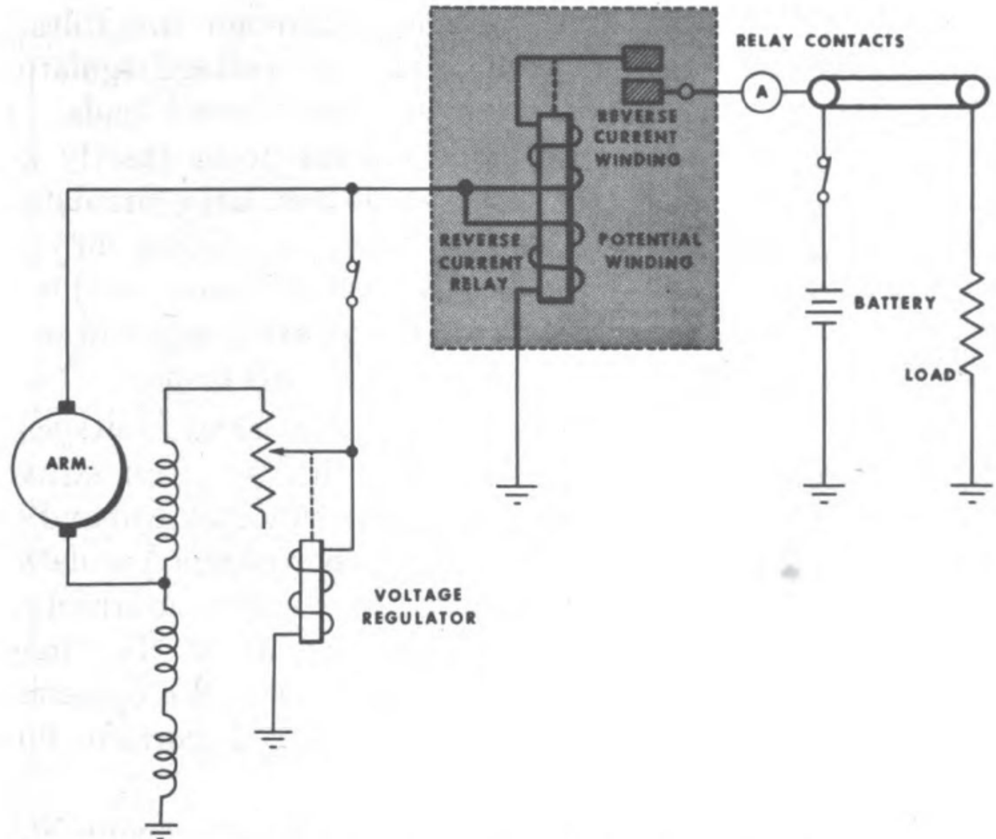


Figure 1–4.—Basic d-c supply with reverse current relay.

ing the contacts closed. The relay points do not open until sufficient reverse current flows through the series winding of the relay to overcome the magnetic effects of the potential coil. This reverse current (from the bus to the generator) occurs when the battery voltage is greater than the generator voltage.

In many aircraft the electrical power requirements are much higher than can be furnished with one generator. For this reason, two or more generators are usually installed and their power is combined or PARALLELED. This means that their output is connected to the same bus, as in figure 1–5. When operating two or more generators in parallel, it is essential that each generator take its proportional share of the total load so that one may not be required to produce more than its maximum rated current while another runs underloaded. To equalize the load between generators it is necessary to make each generator

produce exactly the same voltage. Although the voltage of each generator is closely controlled by its voltage regulator, the voltage of each may not be the same for all loads. If two or more generators which do not maintain exactly the same voltage are connected to the same bus, large circulating currents will flow between them. These circulating currents waste energy and heat the generators. Because of this, a means of control is necessary when operating generators in parallel to equalize the voltage output for all loads.

In a generator paralleling system, the same voltage is maintained by each generator through the use of an EQUALIZER CIRCUIT. This circuit includes an equalizer coil and an adjustable paralleling resistor on each voltage regulator. The equalizer coil is mounted on the same magnetic structure as the operating coil of the voltage regulator. The magnetism of the equalizer either aids or opposes the operating coil flux, depending upon the direction of current flow through the coil.

Figure 1–5 shows two generators of equal rating connected for parallel operation. Added equalizer circuit elements for parallel operation are shown in heavy black lines. In this case, the equalizer resistors have been connected from the negative brush to ground so that the total current supplied by each generator causes a proportional voltage drop across its paralleling resistor.

When both generators supply equal current the voltage drop between the individual negative generator brushes and ground is the same. When the negative brush of each generator is at the same potential no current flows in the equalizer circuit, provided the setting of the equalizer resistors is correct.

Assume that a condition occurs in which generator *A* takes more than its share of the load. Because more current is being supplied by generator *A* than by generator *B*, a greater voltage drop appears across paralleling resistor *A* than occurs across paralleling resistor *B*. The contact on resistor *A* is at a more negative potential than the contact of resistor *B*, and current flows from resistor *A*, through the

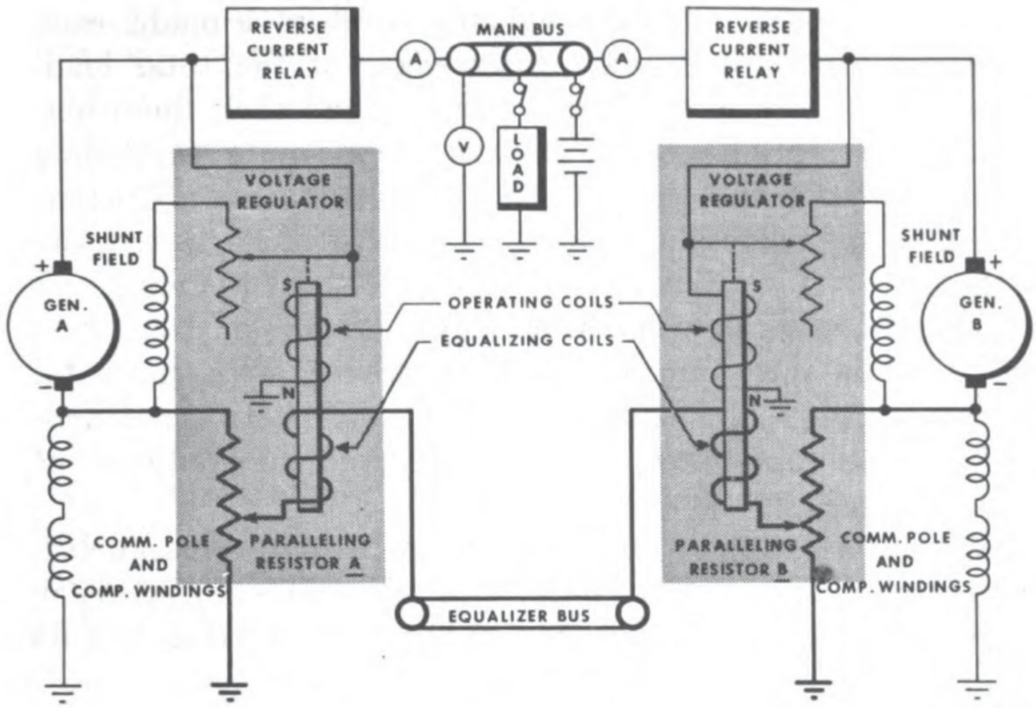


Figure 1–5.—Parallel operation of d-c generators.

equalizer circuit, to resistor *B*. When current flows in this direction the equalizer coils are wound in such a way that the equalizer coil *B* opposes the action of its operating coil, and equalizer coil *A* aids the action of its operating coil. This action decreases the field resistance (increases excitation) of generator *B*, and increases the field resistance (decreases excitation) of generator *A*. This results in a decrease in load current supplied by generator *A* and an increase in current supplied by generator *B*, thereby equalizing the load.

Should the current load of *B* become greater than that of generator *A*, current flow would then be from resistor *B* to *A*, which would in turn cause greater field excitation on generator *A* and less excitation on generator *B*. The more the loads tend to differ, the greater will be the unbalance current between them and the greater the equalizing action.

Often more than two generators are connected in parallel in the same manner as that illustrated in figure 1–5. As long as their respective voltage-regulator equalizing components are connected to the common equalizing bus and

proper adjustment of the equalizing resistors is made, each generator will assume its proper share of the total load. When one generator takes more or less load than the other, a difference of potential will exist between its paralleling resistor contact and that of the other generators. Current will then flow through the equalizer coils of all the generators with the total current flowing through the equalizing coil of the unbalanced generator. The action on the field resistance is the same as before; however, with the total current through the equalizer coil of the unbalanced generator, maximum action will occur on the field excitation of that machine.

When generators of unequal current rating are paralleled, the paralleling resistors must be adjusted so that each generator takes a percentage of the load proportional to its rating.

Paralleling adjustments are usually ground maintenance procedures requiring the use of calibrated voltmeters and a specific procedure. Unless the plane is equipped with suitable meters, such adjustments should not be attempted in flight due to the danger of raising the d-c bus voltage beyond allowable limits.

AIRCRAFT ALTERNATING-CURRENT CIRCUITS

In aircraft power systems, a number of advantages are gained by the use of alternating current rather than direct-current power. Alternating voltages can be easily increased or decreased by the use of transformers, and hence are more flexible than d-c voltages. In a-c machines the use of brushes is minimized and the commutation troubles experienced at high altitudes are thereby reduced. Operation of circuit breakers under a-c load at high altitudes is much more satisfactory than in the d-c system. A marked increase is taking place in the installation of special electronic equipment which requires an alternating-current supply. Where aircraft structure permits the use of a-c generating machines coupled to the engine, the installation of heavy inverters is thereby reduced or eliminated.

Since the a-c power requirements of different aircraft

vary with their type and use, the a-c power supply equipment also varies. Most a-c systems provide one or more sources of 115/200-volt, three-phase, a. c. and of 115-volt single-phase a. c. When the system is connected for three-phase operation either 200 or 115 volts are available at the bus. By proper connection to the three-phase bus, 115-volt, single-phase operation is also possible. The frequency of the alternating current supply is either 400-cycle, fixed frequency, or is a variable frequency from 400 to 900 cycles-per-second, depending upon the method of drive, coupling of the generator, and the equipment being supplied.

The source of a-c power is either an engine-driven a-c generator (alternator), or inverters which are electrically-driven from the primary direct-current system. In many aircraft, where the a-c power need is large, a combination of these sources and types of power is common.

In contrast to the 28-volt d-c generators, the magnetic field coils (called rotors) in most aircraft alternators are rotated, and stationary windings (called stators) then pick up the induced alternating currents. By making the higher-voltage output windings stationary, and by rotating the lower-voltage magnetic field, the use of brushes and their characteristic sparking at higher voltages is reduced. Most alternators in use are individually-excited; that is, the magnetism of the rotating field is produced by electromagnets which obtain direct current for excitation from a small d-c generator which is connected to the same shaft as the rotor field, and which is contained within the same housing as the alternating-current portion of the machine.

Since the electrical equipment supplied by the alternator is designed to operate at a certain voltage and frequency, the speed of the alternator must be regulated. The speed is either held constant, or is held within a certain range so as to produce frequencies usually from 400 to 900 cycles. Because the engine speed varies, the alternators are not connected directly to the aircraft engine. The shaft upon which the rotor of the alternator and the armature of the d-c exciter are wound is coupled to the engine through a constant speed drive unit. A speed control device is then

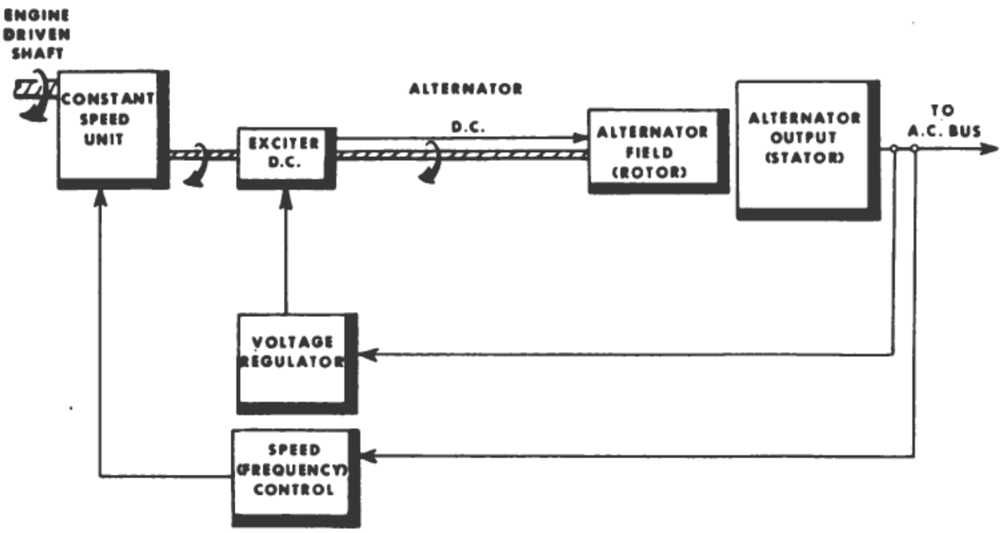


Figure 1–6.—Block diagram of a-c supply.

used to adjust the alternator speed which determines the output frequency.

Figure 1–6 is a block diagram of a typical engine-driven a-c supply. The armature of the d-c exciter and the rotating magnetic field of the alternator are wound on the same shaft and coupled to the engine through the constant-speed drive unit. The d. c. generated by the exciter excites the rotating electromagnetic field of the alternator. An alternating current is then induced in the stationary windings of the stator. The number of stator windings determines the number of independent voltages, or phases, of the machine. In a single-phase generator there is a single stator winding, and in a three-phase generator there are three stator windings. The windings of the three-phase alternator are so spaced and wound that the voltages generated are 120 electrical degrees apart.

A portion of the output voltage is rectified in the voltage regulator. The action of the resulting rectified current through a carbon pile unit in the regulator controls the excitation current in the shunt field of the d-c exciter, and thereby controls the output of the exciter. This, in turn, regulates the excitation of the alternator field in opposition to any change in the output voltage.

Because frequency changes of the output must be held to a minimum, a speed controlling device is incorporated into

most alternator systems. Adjustments in the speed control provide frequency control of the alternator through the constant speed drive unit. This circuit is also adjusted when it is desired to operate two a-c generators in parallel. If the generators of an a-c system are operated in parallel, their output must be in phase at all times. The speed control detects and indicates the frequency and phase of the output and provides a means of controlling the alternator speed.

Many aircraft three-phase circuits are 4-wire systems employing individually-excited alternators with wye-connected stator windings. The neutral connection of the wye is connected to ground. The voltages available at the bus are 200 volts for a normal three-phase connection and 115-volts single-phase. When single-phase connections are made on a three-phase supply the single-phase loads should be evenly distributed over the windings.

Figure 1–7 is a basic schematic diagram of a typical three-phase a-c supply system and contains the essential circuit elements of the alternator and the voltage regulator.

When the engine-driven d-c exciter armature is rotated, its coils cut the residual magnetic field existing in the poles of its shunt field. The small induced voltages in the armature winding are collected at the brushes and serve to further excite the shunt field of the d-c armature. As the speed of the armature increases, the strength of the field also increases in proportion to the speed. Current flows from the negative brush of the armature through the shunt and the series carbon pile resistance to the positive brush of the armature. The rotating magnetic field of the alternator is connected in series with the d-c exciter output, and the direct current thus generated flows through the alternator rotor winding, producing a steady electromagnetic field which revolves at the same speed as the d-c armature.

The revolving field induces voltages in the three wye-connected stationary windings on the stator. Since these windings are wound 120 electrical degrees apart, three-phase output voltages are produced at the output terminals.

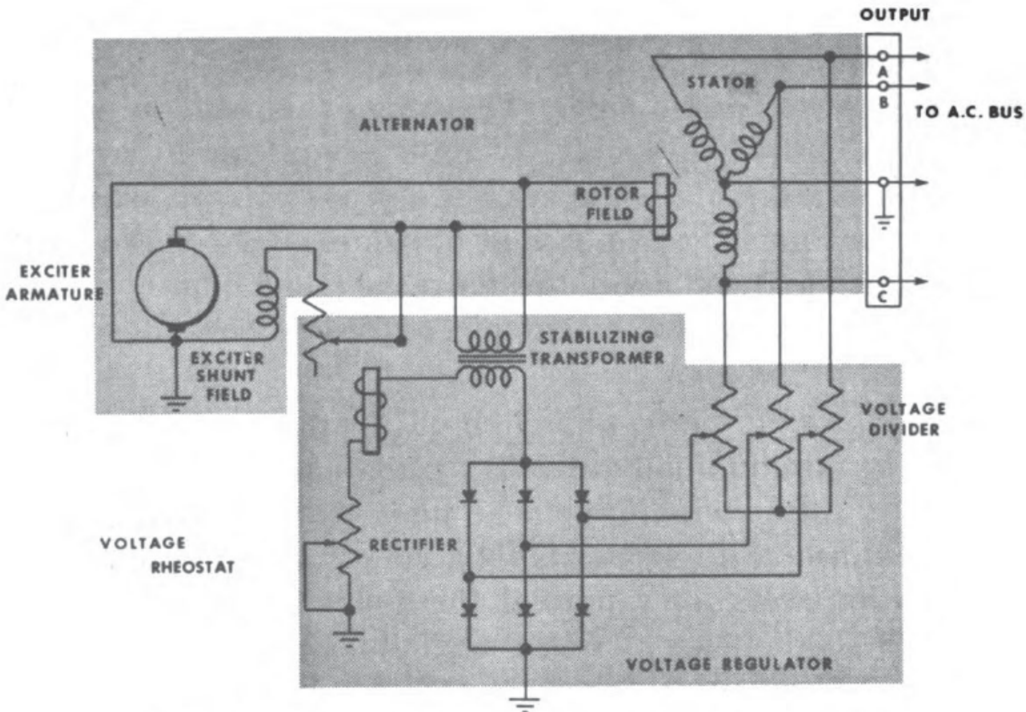


Figure 1-7.—Basic schematic of typical 3-phase supply.

Across the output terminals are connected divider and rectifier circuits (located in the voltage regulator unit) which rectify a portion of the output. The direct current thus rectified normally flows through the stabilizing transformer, the operating coil of the carbon pile, and down through the voltage adjusting rheostat.

The action of the carbon pile is the same as in the d-c voltage regulator: Any increase in voltage at the output terminals increases the current flow through the operating coil of the voltage regulator, which causes more resistance in the field circuit of the d-c exciter, thus decreasing excitation. In turn, excitation of the alternator field is decreased, and a decrease in the output voltage of the alternator results, bringing it back to its normal value. A decrease in the voltage at the output terminals results in less current flow through the operating coil of the carbon pile unit, more excitation of the d-c exciter, increased excitation of the alternator field, and increased voltage at the output terminals.

The stabilizing transformer serves to reduce or dampen the

sudden voltage changes at the output terminals due to sudden changes in the load.

In those aircraft where conditions do not permit installation of sufficient engine-driven alternators, the inverter is used as an additional source of alternating current.

AIRCRAFT STORAGE BATTERIES

Aircraft storage batteries are used to provide a reserve source of electrical energy for operating various units of aircraft electrical equipment. During normal engine operation, engine-driven generators serve as primary sources of electrical power and also maintain the battery (or batteries) in a charged condition. Batteries are not properly employed for ground checking or for engine starting except in cases of emergency. Power for these purposes is normally supplied by auxiliary power units.

A battery is a combination of cells. Any cell consists of at least two plates composed of unlike materials which are immersed in a conducting substance called an ELECTROLYTE. Cells produce electric current and voltage by means of chemical action. The two basic kinds of cells are primary and secondary cells. Primary cells cannot be recharged efficiently after they are exhausted. Secondary cells are based on chemical reactions which are completely reversible; and after they are discharged, it is possible to bring them back to their former condition of usefulness.

In principle, aircraft and automotive batteries are similar, and both are examples of the lead-acid battery. These batteries are made of groups of lead cells, the plates of which are immersed in a solution of sulfuric acid in water. The acid solution is the electrolyte. The battery cells are connected in series by lead connectors welded to the cell posts. Six cells are required for 12-volt aircraft batteries, and twelve cells are used in 24-volt batteries.

The complete aircraft battery is enclosed in a grounded aluminum-covered housing which shields the battery and its terminal connections. The shielding material assists in suppressing the effects of radio-frequency interference which

is often produced in the electrical system. The aluminum container is protected on the inside by a special type of acid resisting lining, and on the outside by use of acid resisting lacquer.

Battery Components

Each cell of the lead-acid battery contains a set of negative plates which are interleaved with a set of positive plates. The active material of the negative plates is pure sponge lead. The active material of the positive plates is lead peroxide (sometimes called lead dioxide). Both sponge lead and lead peroxide are comparatively poor conductors of electricity, but they have the chemical properties necessary in a secondary cell. Both materials are soft and lack sufficient rigidity to allow shaping them directly into plates. As a result, the active materials are applied to supporting frames, called GRIDS. The grids are made of an alloy of lead and antimony and are good conductors of electricity. They are also strong enough to provide rigid support for the active materials of the cell plates. The appearance of the grids is shown in figure 1–8, which is an exploded view of the lead-acid cell.

The vent cap shown in the figure is of a special construction in aircraft batteries. The cap is made of hard rubber and has a very small vent hole which allows the escape of gas formed during the chemical reactions of the cell. When the aircraft is maneuvering or in inverted flight, spilling or leaking of the electrolyte is prevented by the design of the cap. It contains a conically-shaped lead insert which drops against the vent opening and prevents leakage when the battery is inverted, but allows the vent hole to be uncovered when the battery is right side up.

The amount of electrical energy which can be produced by the action of a single plate is rather small, so that a number of plates are grouped together in a cell to give a large surface area, which results in greater battery capacity. As shown in the figure, each plate has an extension by which it is connected to a strap to form a positive group and the negative plates are connected in the same manner.

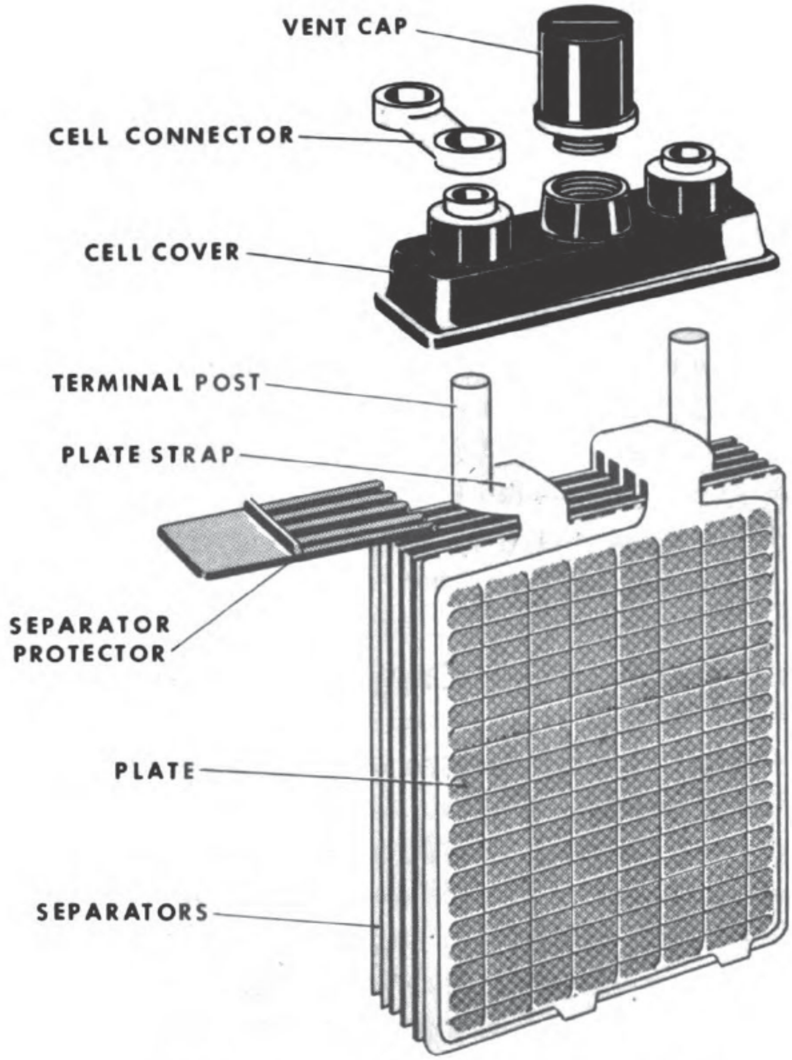


Figure 1-8.—Exploded view of lead-acid cell.

Battery plates must be separated so that they cannot touch each other. Thin porous sheets of insulating material called SEPARATORS are inserted between the positive and negative plates to keep them apart. The separators are made either of wood or rubber, and they are perforated with very small holes through which the electrolyte can easily flow. The separators are grooved on one side and are placed with the grooves next to the positive plates. This allows free circulation of the solution between the plates and also permits the material which is shed from the positive plates in normal operation to fall to the sediment chamber at the bottom of the cell. (Shedding of material is more rapid on the positive

plates than on the negative—the positive assembly wears out much quicker than the negative plates.)

The meshed positive and negative groups of plates, together with the separators, constitute a cell element. The plates are arranged alternately positive and negative with all positive plates connected through a strap to a positive post on one side of the cell. All the negative plates are attached to a similar strap and joined to a negative post on the opposite side of the cell. The negative group always has one more plate than the associated positive group. This equalizes the expansion of the active positive material which occurs during discharge of the cell. It also provides an excess of negative plate area, which is required for good battery performance.

Action During Charge and Discharge

In the original manufacture of the lead-acid battery, the active plate material, lead and lead peroxide, is produced by a process called FORMING. The substances from which the active materials are made are first applied to the grids in the form of paste. A mixture of commercial red lead and dilute sulfuric acid is applied to the negative lattice and a mixture of yellow lead oxide and sulfuric acid is applied to the positive grid. The paste has about the same consistency as soft plaster, and after it has dried, the plates are given an electrochemical treatment, or forming process. The procedure consists of passing electric current through the plates which are suspended in a solution of sulfuric acid and water. This treatment converts the lead oxide into lead peroxide in the positive grid. Pure sponge lead is produced in the negative grid. When completely formed, the positive material is chocolate brown and the negative material is light gray in color. After the process is completed, the plates are washed, dried, and assembled.

During discharge of the cell, the sulfuric acid in the electrolyte reacts with both plates to form lead sulfate. The sulfuric acid itself breaks up into ions—positively charged ions of hydrogen and negatively charged sulfate ions. The

sulfate ions unite with the lead in the plates to form lead sulfate. The positive hydrogen ions combine with the oxygen atoms in the lead peroxide to form water. During discharge, the sulfuric acid is decreased in quantity and the water is increased in quantity. The chemical action results in the presence of free electrons being made available at the negative terminal. These free electrons flow through the external circuit connected to the battery terminals and their flow constitutes the discharge current of the battery. Continued discharge carries on the process of converting the active material of both sets of plates into lead sulfate. If it is carried on long enough, all the active material becomes converted, but voltage at the terminals of the cell ceases before the two sets of plates are reduced completely.

Two important actions occur during discharge: conversion of the active plate material to lead sulfate, and reduction of the sulfuric acid in the electrolyte, causing the solution to become weaker.

The condition of the cell may be determined by measurement of the specific gravity of the electrolyte. The specific gravity of a liquid is the weight of a given volume of the liquid divided by the weight of the same volume of water. The electrolyte in fully charged batteries has a specific gravity of 1.275 to 1.300. The specific gravity of the electrolyte of a fully discharged battery is from 1.100 to 1.150.

Specific gravity is measured by use of a hydrometer. This instrument usually is a small sealed glass tube weighted at its lower end so it will float in an upright position. In the stem of the tube a paper scale is placed on which the specific gravity reading is made. The hydrometer is enclosed by a glass syringe into which enough liquid is drawn to float the hydrometer bulb. The depth in the liquid to which the hydrometer sinks is read against the scale placed in the hydrometer stem.

When the battery is charged, a chemical action which is the reverse of that occurring during discharge takes place. To charge the battery, current is forced through the cells by application of an external d-c potential. Electrons applied by the charging source to the negative terminal com-

bine with any positive lead ions there to form pure sponge lead. The sulfate ions present on the plates recombine with hydrogen to form sulfuric acid. The amount of water present is diminished and the amount of sulfuric acid increases during the charging process. The action of the charging current again produces lead peroxide at the positive plates and pure lead on the negative plates as was the case in the original action of forming the cell. When all the lead sulfate is converted, the battery is fully charged, the electrolyte reaches its former specific gravity of 1.300, and the battery is again ready to supply electric energy.

Capacity

The amount of electrical energy within a battery is measured in ampere-hours. The term AMPERE-HOUR may be defined as the number of amperes flowing, multiplied by the time in hours during which the flow takes place. A battery which is discharged at 2 amperes for 10 hours furnishes 20 ampere-hours. The energy involved might be replaced by charging it for 5 hours at 4 amperes. The capacity rating of an aircraft battery is based on the maximum current which it will deliver for five hours, with a starting temperture of 80 degrees F., and a final terminal voltage of 1.75 volts per cell. This is called the battery's five-hour discharge rate. The capacity of the battery is this rate multiplied by five. For example, a battery in which a current of 7 amperes (at 80 degrees F.) is sufficient to lower the individual cell voltage to 1.75 volts in 5 hours has a capacity of 7×5 or 35 ampere-hours.

The open circuit voltage of a cell depends on the material of which the plates are made and is not affected by the size or number of plates. The plate material changes during discharge and as a result, the voltage also changes. The open circuit voltage of a fully charged lead-acid cell is approximately 2.2 volts. This soon drops to about 2.0 volts at a low discharge rate and remains near that point until the battery is practically discharged, after which the voltage per cell drops rapidly.

Maintenance of Aircraft Batteries

Aircraft storage batteries give trouble-free performance throughout long periods of time provided certain precautions are taken to insure proper operation. Maintenance of batteries consists principally in keeping the terminals clean and the connections tight, in checking the water level in the cells at regular intervals (with addition of water when necessary), and in maintaining the batteries in a state of charge.

Cleaning

In cleaning the battery, corrosion is removed from the terminals by brushing with a stiff brush (but not a wire brush). The terminals are then washed with a solution of bircarbonate of soda in water. The solution is made by adding one pound of sodium bicarbonate for each gallon of water. This solution neutralizes any electrolyte which remains on the terminals after washing. The terminals are then dried and a thin coating of terminal grease or vaseline is applied to the metal terminals.

Parts such as washers or wingnuts on which the lead coating is worn or scraped off should be replaced.

Vent caps should always be kept in place during cleaning of the top of the battery and the terminals. Afterwards, the caps should be carefully inspected to be sure that the gas escape holes are clear.

When it is necessary to remove the battery from its mounting in order to clean or service it, all battery switches should be turned off before removal of the battery terminal leads.

Addition of Water

If the electrolyte level can be seen and if specific gravity readings can be taken, no water need be added. When it is necessary to add water, distilled water should be used whenever possible. If distilled water is not available, clean drinking water may be added. If the liquid level in the cells cannot be seen, add water to a level ⅜ inch above

the top of the separator plates. The addition of too much water will cause the electrolyte to leak from the vents when the plane is in operation.

The self-leveling syringe, shown in figure 1–9, is used in filling the cell. The syringe is filled with water and inserted in the cell opening in a vertical position. Water is added by squeezing the bulb. Excess water is drawn back into the syringe until air is sucked in. This leaves the electrolyte at the proper level.

If the battery is exposed to temperatures below freezing, no water should be added unless the battery will be charged immediately afterward. Charging causes the water to become thoroughly mixed with the electrolyte. Unless this occurs the water remains on top of the liquid and may freeze.

Hydrometer Readings

Hydrometer readings are made periodically to determine the electrolyte's specific gravity, which indicates the state of charge of the cells. Just enough liquid should be drawn into the instrument to raise the float from the position in which it normally rests. The reading is taken at eye level as illustrated in figure 1–10.

The state of charge is indicated by the reading. For example, the following is a summary of approximate states of charge for various specific gravity readings:

Fully charged	1.275 to 1.300
One-third discharged	1.240 (Replace with fully charged battery if the reading is below this figure.)
Two-thirds discharged	1.200 (Insufficient capacity for satisfactory operation.)
Completely discharged	1.150

To insure accuracy in measuring specific gravity, the temperature of the electrolyte must be taken into account. This is done by the use of a Temperature Corrected Hydrometer. This instrument is equipped with a thermometer which measures the solution temperature, together with a scale which gives a correction figure to be added to or subtracted from the float reading for each temperature value.

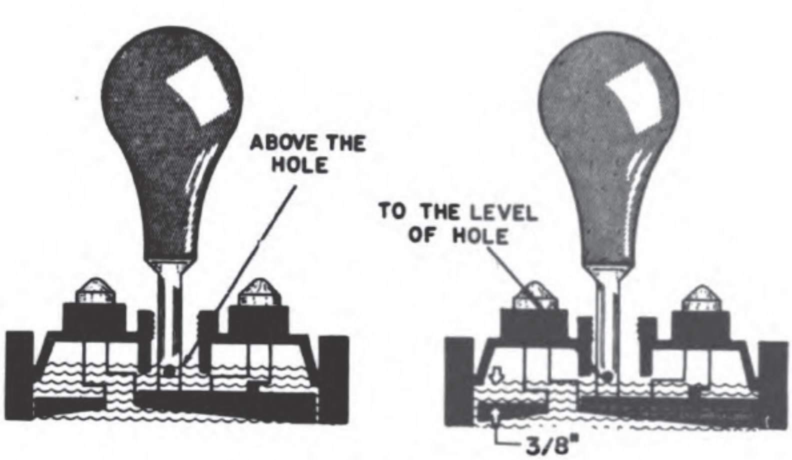


Figure 1–9.—Self-leveling syringe.

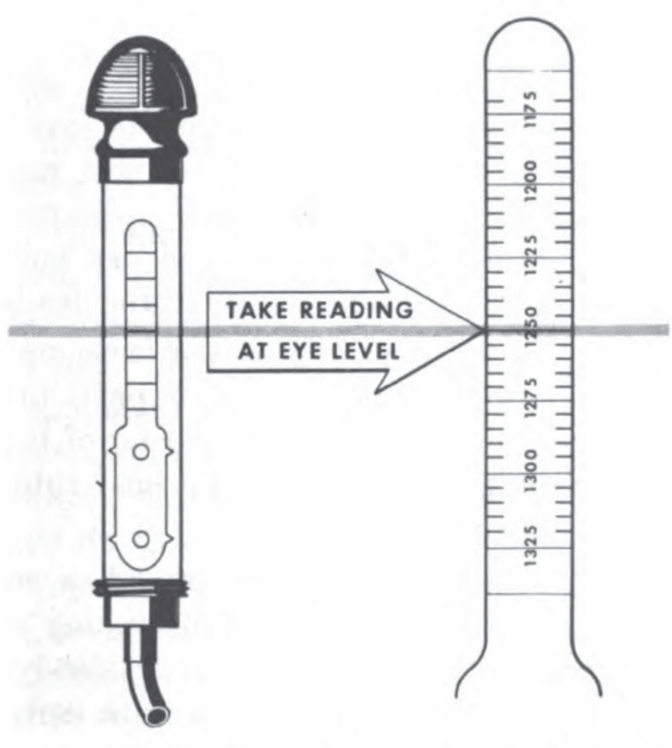


Figure 1–10.—Testing specific gravity with hydrometer.

Batteries must be charged when the electrolyte specific gravity is 1.240 or lower. Before placing the battery on charge, it must be prepared in the following manner:

1. The top of the battery and the outside of the case are cleaned with a hose and plenty of water. A bicarbonate of soda solution is applied to the terminals after any corrosion

has been removed by brushing. The general physical condition of the battery is checked.

2. The filler caps are removed and water is added if necessary.

3. Batteries are charged with direct current only. Groups of batteries can be charged connected either in series or in parallel. The correct method of attaching the charging leads and the batteries to be charged depends on the type of charging equipment available.

4. While the battery is being charged, the vent caps are unscrewed but are left resting loosely in the cell openings to prevent possible spraying of electrolyte over the battery top, and also to prevent foreign matter from falling into the cells.

Extreme care should be exercised when attaching or detaching the charging leads in order to prevent short circuit flashes which might ignite the hydrogen gas generated in the cells during the charging process. The power switch on the battery charger should be in the OFF position prior to connecting or disconnecting the charging leads.

Sulfuric acid or battery electrolyte may cause painful burns if allowed to contact the hands or other parts of the body. Those engaged in the handling or preparing of battery electrolyte should wear goggles, rubber aprons, rubber gloves, and rubber boots or overshoes.

When sulfuric acid and water are mixed, a considerable quantity of heat is produced. When mixing electrolyte, ALWAYS POUR THE ACID INTO THE WATER slowly and with constant stirring. NEVER POUR THE WATER INTO THE ACID. If water is poured into acid, heat may be generated so rapidly that the liquid will boil and drops of acid may be thrown upon the operator. The container should be glass, earthenware, lead-lined wood, or a similar vessel resistant to sulfuric acid.

New batteries are without electrolyte when received from the manufacturer. They should be stored in a cool, dry location and removed for service in the order in which they were received. Any battery which has been stored for 16

months or longer should be tested to determine its capacity before installation.

Batteries containing electrolyte also should be stored in cool, dry places. These batteries must be given a recharge once each month when the surrounding temperature is 80 degrees F., or less, and every two weeks if temperatures rise above that figure.

Batteries no longer fit for service in aircraft should be plainly marked and used on testing devices, battery carts, or other equipment. When completely worn out, they should be emptied of electrolyte and sent to the appropriate activity for salvage.

DYNAMOTORS

Dynamotors are often used in aircraft communication installations and other low-power electronic equipment. They are devices which change the low d-c voltage of the aircraft's primary power system to the higher values of d-c potential required for the operation of the equipment.

The dynamotor is essentially a d-c motor and generator mounted, or wound, on a common form and contained within a single housing. A single stationary field winding is used to provide the magnetic field for both the motor section and the generator section. The armature consists of two sets of rotor windings, both of which are wound on the same core and mounted on the same rotating shaft, but are connected to separate commutators. One winding serves to produce the driving force when energized by the low d-c potential. The other winding generates a high d-c voltage when it is rotated within the magnetic field.

A functional diagram of a typical dynamotor is illustrated in figure 1–11. The single heavy line represents the motor circuit. Relatively high current from the low-votlage source flows through the field coils and the motor winding of the armature, setting up a magnetic field around both. The coils are wound so that the fields interact and thus cause the armature to rotate.

The high-voltage winding, represented by the fine lines between the fields, is wound on the same armature and

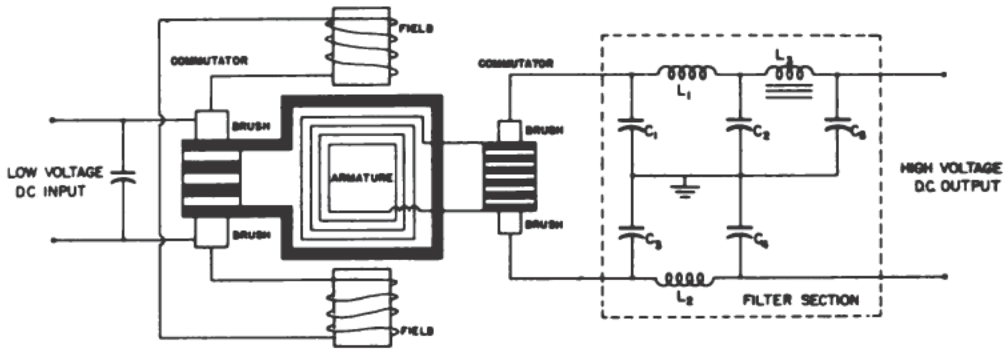


Figure 1-11.—Functional diagram of a dynamotor.

rotates with the motor winding. When turning, the high-voltage winding cuts the lines of force of the common field and generates a voltage which is collected by the brushes at the high-voltage commutator. The greater the number of turns in the high-voltage armature winding the greater will be the output voltage.

Since the armature and field windings in the diagram of figure 1-11 are connected in parallel the motor illustrated is a shunt-wound machine. A desirable characteristic of this type of motor is that the speed remains fairly constant during changes in the load placed upon it.

The high current drawn by the motor necessitates a correspondingly large size in the motor components such as the commutator, brushes, and armature wire when compared to those components of the generator. The motor commutator is larger in diameter but has fewer segments than that of the generator. The generator armature winding contains a large number of turns in order to produce high voltage, since the voltage induced in it increases with the number of turns.

Filters are usually placed at the high-voltage output terminals to filter out high-frequency currents produced by sparking between the brushes and the rotating commutator segments, thereby eliminating any possible interference from this cause. The filter consists of a combination of chokes and capacitors as shown in the typical filter section at the right of figure 1-11. The purpose of the chokes, L_1, and L_2, is to present a high impedance to r-f energy in the external circuits. The low impedance of the capacitors, C_1, C_2, C_3, and C_4, bypass the r-f energy to ground.

Additional filtering is provided to eliminate commutator ripple which is similar to the ripple found in the output of conventional a-c rectifiers. This audio filtering usually consists of a series inductor of comparatively high value and a shunt capacitor. It is represented in the figure by the iron-core choke, L_3, and capacitor C_5. The capacitor across the low-voltage input leads reduces sparking between the brushes and commutator at the input end of the dynamotor.

INVERTERS

An inverter is a machine which consists of a d-c motor directly coupled to an a-c generator within a single housing. The d-c motor, when connected to the aircraft's primary d-c system, drives the alternator which in turn generates an a-c voltage. A cutaway view of a typical aircraft inverter is shown in figure 1–12.

In most cases the d-c armature and the alternator field windings are wound on the same rotor shaft while the d-c motor field and alternator output (armature) windings are wound on the stator. A control box is attached to many inverters in which is contained the necessary devices to control its operation. These devices consist of the operating relays, voltage regulator and rectifier, filtering units, and smaller circuit components. The controls which may require adjustment during flight are usually found in the control box.

The d-c motor portion of most aircraft inverters is essentially a shunt-wound motor. High starting currents and a low rate of acceleration (due to low torque at starting) are characteristic of shunt-wound machines. To avoid the effects of these undesirable characteristics on other portions of the aircraft's d-c system the larger inverters employ a series starting winding. When the machine approaches its normal rated speed, relays disconnect the series starting winding and connect the d-c input directly to the d-c motor armature and the shunt winding. The machine then oper-

ates as a shunt-wound motor which has desirable constant-speed characteristics. In some machines, small compensating and commutating pole windings are used in series with the motor armature, but these windings have no effect on the shunt-motor action.

The d-c motor converts electrical energy into mechanical energy to drive the alternator. The d-c load current drawn by the motor depends on the a-c load on the alternator. The motor speed is controlled by a speed control governor. In most cases, the speed control governor is a device which automatically varies a resistance in series with the motor shunt field. The speed of a d-c motor is inversely proportional to the strength of the field. Therefore, the speed governor automatically decreases the resistance of the shunt field as the motor tends to speed up, and a greater shunt-field current is allowed to flow in the shunt windings, thus reducing the speed. As the motor speed tends to fall below its normal value, the shunt-field resistance is increased, less current flows in the shunt-field windings, and the motor speeds up.

The generated a-c voltage is proportional to the speed of the rotor and the strength of the alternator rotor field flux. The controlled frequency of the a-c output is usually fixed at 400 cycles per second. This frequency is a function of the number of poles in the alternator field and the speed of the motor. The number of independent voltages, or phases, in the output is determined by the number of windings on the stator of the alternator. In some inverters, both three-phase and single-phase outputs are obtained from the same machine; others are equipped to supply only one type of output—either single-phase or three-phase.

The output voltage ratings of aircraft inverters vary considerably, and depend on the type of aircraft in which the machine is installed and the equipment which it supplies. For example, a number of inverters may be installed in the same aircraft. One may be designed to supply 26 volts of single-phase alternating current to an essential bus during emergencies. Another may be used continuously to supply

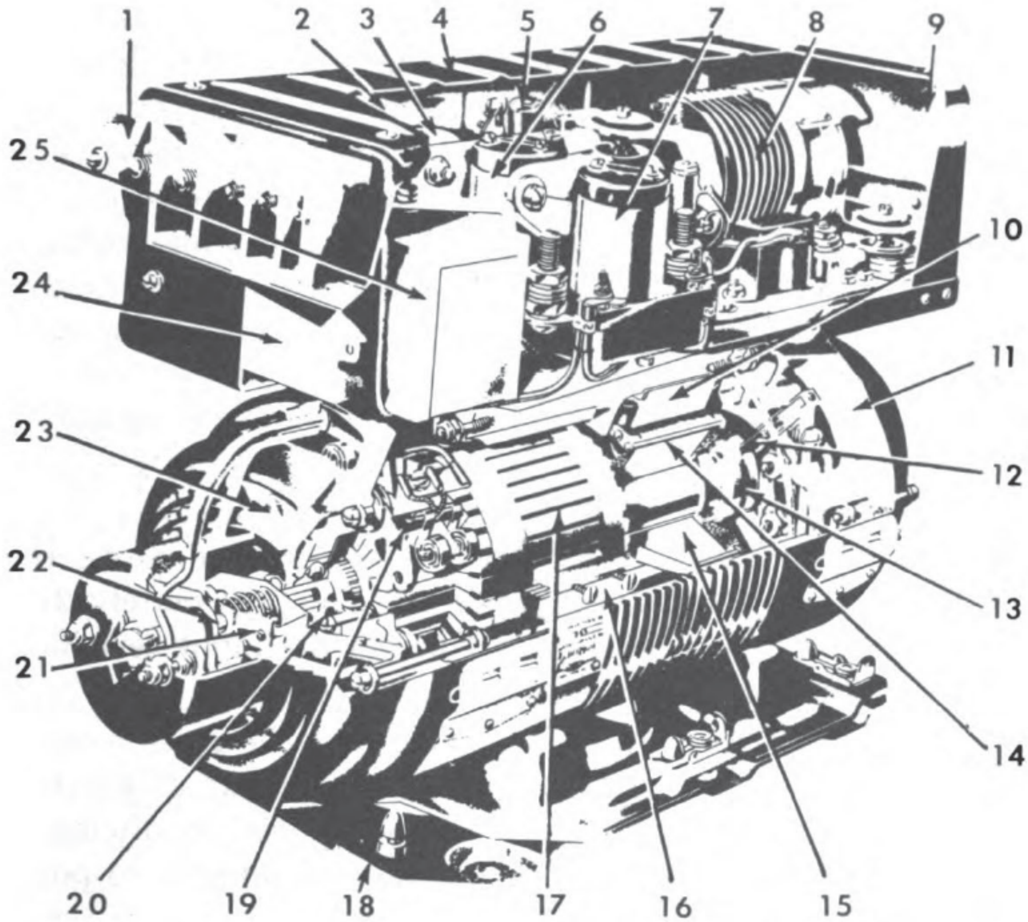


Figure 1–12.—Cutaway view of aircraft inverter.

1. Terminal Block
2. Clare Relay
3. Output Relay
4. Control Box Cover
5. Resistor
6. Running Relay
7. Starting Relay
8. Voltage Regulator
9. Control Box
10. Alternator Stator
11. Motor-Alternator Casting
12. Alternator Brushes
13. Alternator Slip Rings
14. Field Conductor Bars
15. Alternator Field
16. Motor Yoke
17. Motor Armature
18. Sub-base
19. Motor Brushes
20. Ball Bearing
21. Centrifugal Governor
22. Carbon Pile
23. Centrifugal Fan
24. Capacitor Unit
25. Filter Unit

115 volts of single-phase a-c power, while still another may be used to furnish 115/200 volts of three-phase power to a specific bus or equipment.

The output voltage of the machine is usually maintained at an almost constant value by controlling the d-c excitation current in the rotor field of the alternator. In most cases this is accomplished by means of a carbon pile voltage regulator which is controlled indirectly by the terminal voltage. Variation in the output level of the terminal voltage changes the variable resistance of the carbon pile, which is in series with the alternator field, thereby changing the excitation of the a-c rotor field. In turn, the terminal voltage is regulated.

Figure 1–13 is a simplified schematic diagram of a typical inverter such as that shown in figure 1–12. The three-phase alternating current at 115 volts may be obtained across the delta-connected output terminals when approximately 27.5 volts of direct current is applied across the input terminals of the motor.

When d-c input voltage is applied and the main control switch is closed, the input voltage then appears at point *A* and the coil of the starting relay becomes energized, closing its contacts. The input is then connected directly to point *B* and direct current flows through the motor and its series field, starting rotation of the motor. The large voltage drop across *BC* which is due to a high series-field current, energizes the coil of the lower running relay (1), and its normally closed contacts open. As the motor approaches its operating speed, series-field current decreases, thereby decreasing the voltage drop across *BC*, the relay is de-energized, and its contacts close.

When the contacts of the first running relay (1) close, the voltage at the positive brush of the d-c armature is then applied to the coil of the second running relay (2). This voltage is sufficient to energize the coil of the relay (2), its contacts close, and input voltage is then applied directly to the d-c armature and the shunt field, bypassing (shorting out) the series starting field. The motor then operates as a shunt-wound machine.

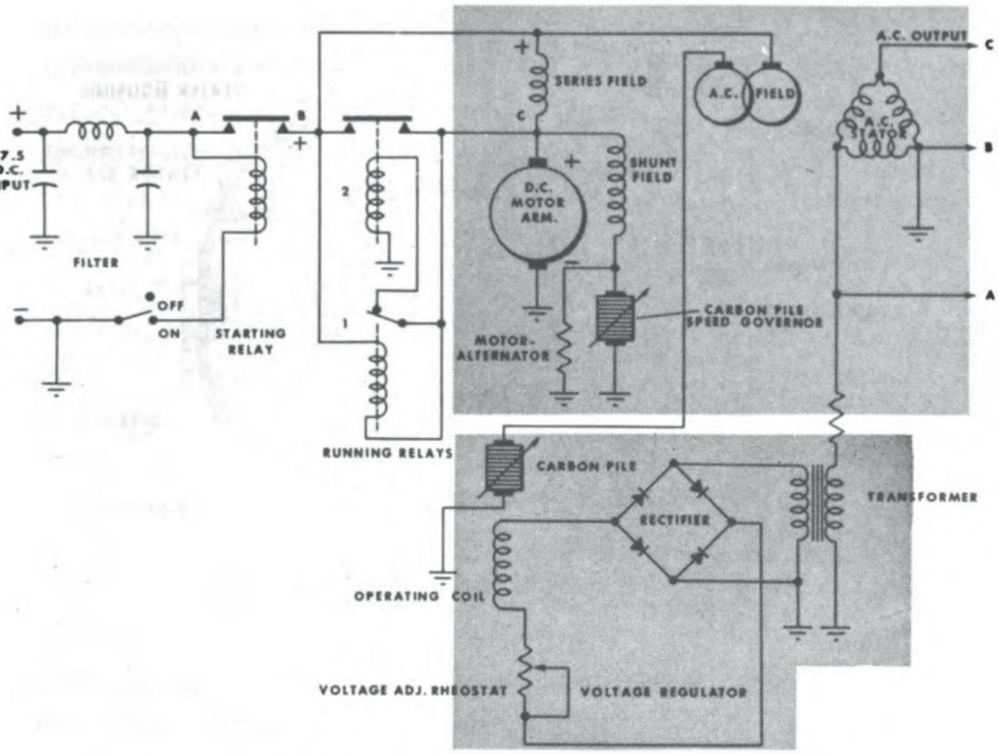


Figure 1–13.—Simplified schematic diagram of aircraft inverter.

When the starting relay is energized, the input voltage at point *B* also serves to excite the rotating field of the a-c alternator through sliprings located on the rotating shaft. Since the alternator field is in series with a carbon pile unit of the voltage regulator, the direct current through the rotor is thereby controlled. The rotating field flux sweeps across the stationary armature windings and induces voltages in them, and three-phase a-c voltage appears across the output terminals.

A portion of the output current (output terminal *A*) is rectified through the step-down transformer and dry-disk full-wave rectifier. The rectified d-c current then regulates the current flowing in the alternating rotor field by its action in the operating coil of the regulator. The action of the carbon pile regulator is the same as that for any d-c carbon pile regulator. The voltage-adjusting rheostat is used to set the operating level of the output.

A functional diagram of a typical speed control governor is illustrated in figure 1–14. The governor consists of two

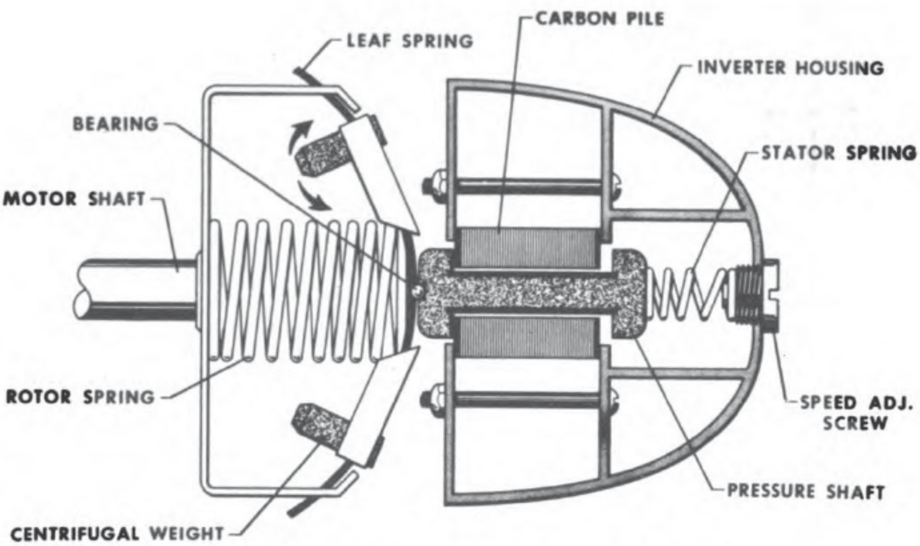


Figure 1-14.—Typical speed control governor.

main parts the rotating portion, which is mounted on the motor end of the d-c armature shaft, and the stationary portion mounted on the end cover of the inverter housing. The motor shaft is extended axially by a coil spring (rotor spring). Centrifugal weights mounted on a leaf spring oppose the action of the rotor spring. The stationary portion of the governor consists principally of a carbon pile, a stator spring with its adjusting screw, and a pressure shaft. As shown in the diagram the pressure shaft extends through the center of the carbon pile with its inner length greater than the length of the carbon pile.

When pressure is applied at either end of the carbon pile, its resistance is decreased. When the alternator is at rest, or rotating at low speed, the centrifugal weights are positioned as shown, with the rotor spring holding the carbon pile at high compression (low resistance) by heavy pressure against the left end of the pile. Minimum resistance results in maximum field current, which gives maximum field flux for good starting characteristics. The force of the stator spring is overcome by the rotor spring action.

As the motor approaches its operating speed, the centrifugal weights on the leaf spring move outward, compressing the rotor spring, and reducing the pressure on the left side of the pile. The resistance of the pile increases with the

reduction of pressure until the right end plate of the pressure shaft comes into contact with the pile. Any further movement of the centrifugal weights above or below the normal operating speed will then cause pressure to be exerted against the right end of the pile. This movement either aids or opposes the action of the stator spring.

If the motor speed tends to increase above the normal operating speed the weights move outward, the rotor spring is further compressed, and the pressure shaft moves to the left, due to the force of the stator spring. More pressure is exerted on the right end of the pile, the pile resistance decreases, and more current flows in the motor shunt field, increasing the field flux. Increasing the field flux of a d-c motor decreases the speed; therefore, the speed of the motor is reduced. Conversely, if the motor tends to slow down below its operating speed, the weights move inward, the action of the rotor spring opposes the action of the stator spring, and the pressure shaft moves to the right. Because of the greater length of the pressure shaft no pressure is exerted on the left end of the pile; thus the pile resistance increases, field flux is reduced, and the motor speeds up.

CARBON PILE VOLTAGE REGULATORS

The output voltage of generators is usually regulated, or controlled, by varying the field current of the machine. The field current is controlled by a variable resistor in series with the field winding. This adjustment may be made to maintain constant output voltage, compensating for variations caused by the effects of changing load current, temperature changes, or for changes in generator speed.

Adjustment of the series resistance, and hence of the field current, may be made manually if the voltage changes are slow. Usually some form of automatic adjustment of the field current is necessary if the generator is to maintain a reasonably steady output.

Aircraft voltage regulators ordinarily are of the carbon pile type. The essential element of the carbon pile regulator is a variable resistance consisting of a stack of carbon disks, or washers. The carbon pile unit is placed in series with the

field winding of the generator to be regulated, and the resistance of the carbon stack is varied when the output voltage changes.

Compression of the stack of carbon disks results in a decrease in the resistance of the unit. When the pressure against the disks is relaxed, the resistance increases. A spring is used to hold a constant pressure on the carbon unit and this tends to compress it. Variation of the resistance is accomplished during operation by the magnetic action of a potential coil which opposes the force impressed on the pile by the spring. The connections of the carbon pile, the potential coil, and the generator shunt-field windings are shown in figure 1–15.

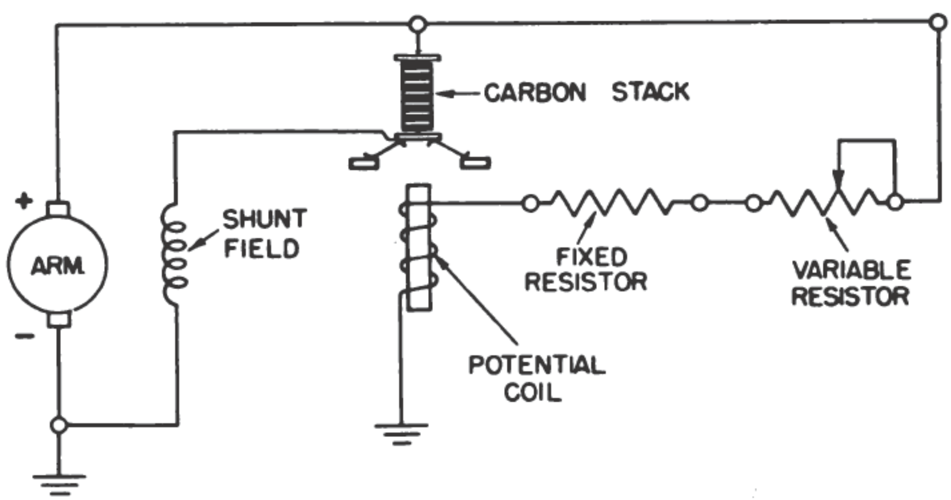


Figure 1–15.—Schematic diagram of a d-c carbon pile voltage regulator.

The potential coil is connected across the output of the generator. Any increase in generator voltage causes an increase in the current in the potential coil, resulting in greater magnetic field. The magnetic field opposes the force of the wafer spring and reduces the compression of the carbon pile. The resistance of the pile is increased and this lowers the amount of field current in the generator winding, resulting in a decrease in generator output voltage.

If the output voltage falls, the potential coil draws less current, its magnetic attraction decreases, the force on the wafer spring compresses the carbon pile, and this allows

greater field current to flow in the generator, causing the output voltage to rise.

Two resistors are in series with the potential coil. The variable resistor is a rheostat which provides a method of adjusting the output voltage of the generator when the regulator has just been installed in the aircraft. (The major adjustments of the regulator are made on a test stand external to the aircraft, and since the test lead resistance is usually different from that of the connecting leads in the aircraft minor adjustment may be required at the time of installation.) The fixed resistor is larger in value than the rheostat and serves as a current limiting device.

The details of the construction of the regulator are shown in figure 1–16.

The carbon pile disks shown in the figure are placed in a ceramic insulating cylinder. The cylinder is mounted in a metal housing which serves to dissipate the heat generated in the carbon stack as well as to support the assembly. One end of the carbon stack rests against a button which is adjusted in position by means of a pile screw. The other end of the stack rests against a button which is positioned by a movable plate called an armature. The armature exerts force on the carbon pile by means of the tension of the armature spring.

The potential coil is wound around a movable soft iron core. The position of the core is adjusted by means of a core screw which is shown at the right of the figure.

The regulator illustrated is equipped with a mechanical stabilizer which encloses a coiled suppressor spring. This spring exerts a force on the armature by means of a shaft, and this force assists the pull of the potential coil on the armature. The stabilizer largely eliminates the tendency of the regulated voltage to rise as the carbon disks wear. It also decreases the tendency toward instability in the regulator when the output voltage is changing rapidly.

Many carbon pile regulators are equipped with equalizer coils (not shown in fig. 1–16). The equalizer coil is wound around the core of the potential coil and is used in conjunction with an equalizer resistor which is mounted in the base of the regulator. The equalizer coil operates only when the

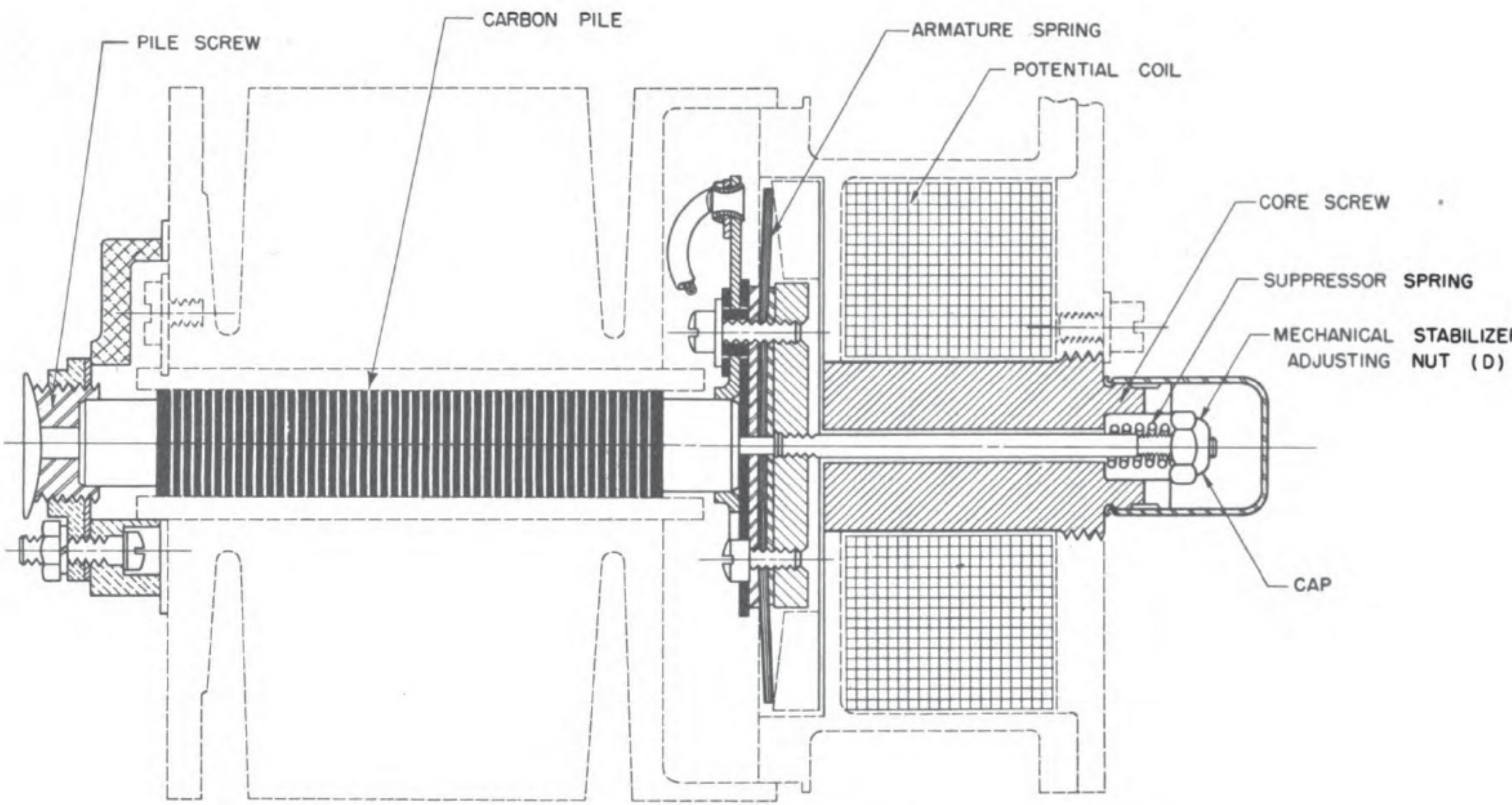


Figure 1-16.—Carbon pile regulator with mechanical stabilizer.

generator controlled by the regulator is connected in parallel with similar generators.

Carbon pile regulators are used to regulate the output of a-c alternators as well as d-c generators. The principle involved in a-c regulation is identical with that of d-c regulation: the carbon pile resistance is made to vary as the output voltage varies, controlling the field current of the alternator. When regulating alternating voltage, the potential coil of the regulator is provided with direct current derived from a selenium rectifier circuit which rectifies a portion of the alternating output voltage of the generator. Changes in a-c voltage result in changes in the rectified current flowing through the potential coil, and this in turn adjusts the field current of the alternator by means of variation in the resistance of the carbon pile. The basic arrangement for a-c regulation is shown in figure 1–17.

In alternators or inverters which supply high current to equipment such as radar units, the output voltage makes an abrupt jump in value when the equipment is switched ON or OFF. The associated carbon pile regulator is forced to make a large correction as it attempts to hold the voltage constant. If this correction is made too quickly the regulator may be driven into a series of overcorrections in the line voltage,

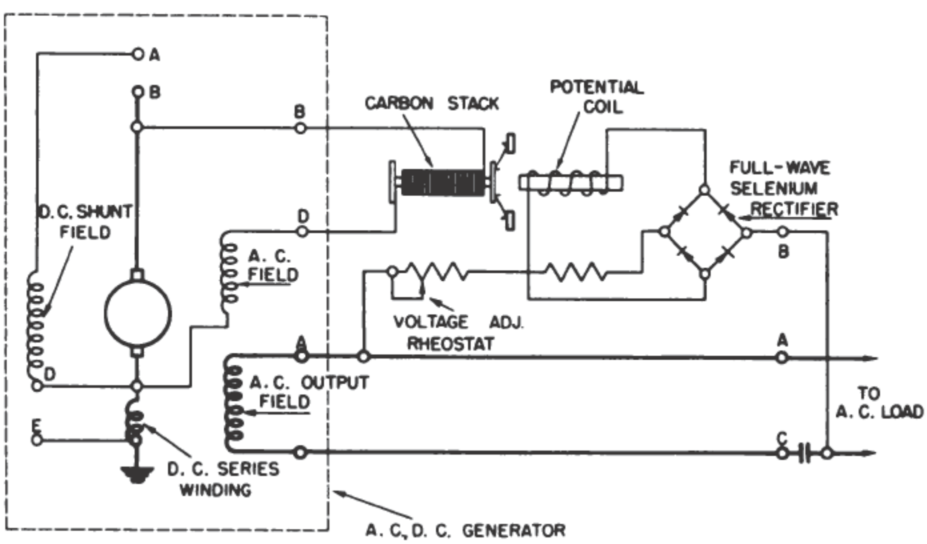


Figure 1–17.—Schematic diagram of a-c carbon pile voltage regulator.

causing the alternator output to oscillate about the correct value. This condition is called HUNTING.

Overcorrection may be prevented by the action of a circuit which allows the regulator to make slow changes only, and which damps out oscillation. A circuit of this kind is called a stabilizing, or antihunt, circuit and usually consists of a transformer. The transformer induces a voltage in the circuit of the potential coil of the regulator in such a way as to oppose changes in the coil current. (It is similar in principle to negative feedback in electronic amplifier circuits, which tends to stabilize the amplifier and to prevent oscillation.)

The circuit of a stabilizing transformer used with a carbon pile regulator is shown in figure 1–18. The figure illustrates the application of the stabilizing transformer to an alternator.

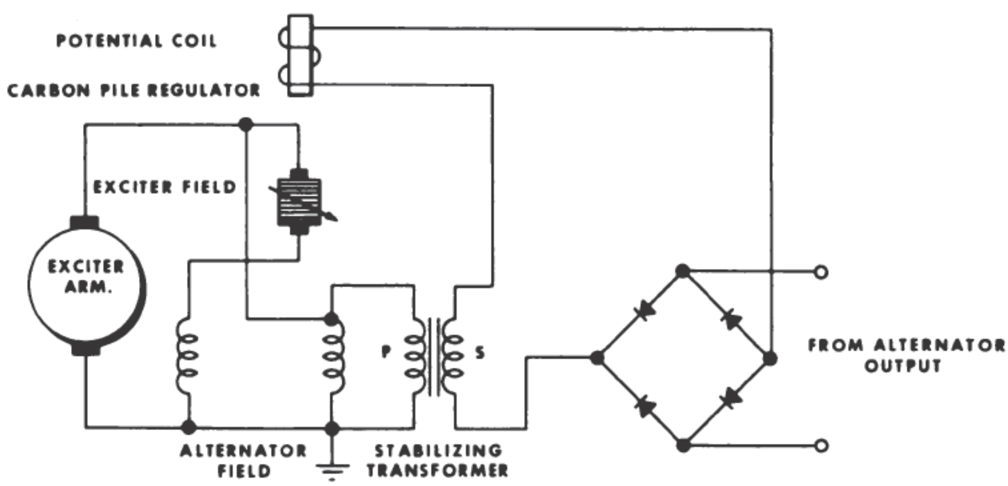


Figure 1–18.—Stabilizing transformer circuit.

The primary of the stabilizing transformer is connected in parallel with the alternator field winding. Any rapid change in alternator field voltage induces a sizable voltage in the circuit of the regulator potential coil. Slow changes in field voltage produce low induced voltage in the secondary of the transformer and hence have almost no effect on the action of the regulator. The stabilizing voltage, then, depends on the rate at which the alternator field changes in current and voltage. The polarity of the induced voltage

is such that any rapid change in potential-coil current is opposed. With increasing coil current, an induced voltage results which partially cancels the voltage acting on the potential coil. With decreasing coil current, an induced voltage results which aids the voltage of the potential coil. Since the amount of the induced stabilizing voltage varies with the rapidity of the change made by the regulator in the field current, changes in the control current must be made slowly, and any tendency to overcorrect and oscillate is damped out.

Regulator Adjustments

The four primary adjustments of the carbon pile regulator are as follows (refer to fig. 1–16):

1. Series rheostat. The rheostat in series with the potential coil provides for output voltage adjustment at the time of installation of the regulator in the aircraft. It is also adjusted to compensate for pile wear.
2. Core screw. This adjustment provides for control of the magnetic air gap between the armature and the core of the potential coil. The core screw is primarily a voltage adjustment, although regulating characteristics are also affected by it.
3. Pile screw. The pile screw adjustment controls the degree of pile compression and the armature position. The pile screw adjusts the regulating characteristics of the device, although the output voltage is also affected by it.
4. Mechanical stabilizer nut. The adjusting nut on the stabilizer controls the amount and characteristics of armature travel. It affects the regulating characteristics and the amount of allowable pile wear before instability in regulator action and appreciable voltage change occur.

These adjustments must be carefully made by competent personnel using the proper test and measuring equipment. They must be made in accordance with detailed adjustment instructions pertaining to the particular regulator in question. With the exception of the series rheostat adjustment (which is made at the time of installation of the regulator

in the aircraft) all adjustments are made with the regulator on a test stand. They are done in the aircraft only in cases of emergency.

AIRCRAFT ELECTRICAL CONTROL AND PROTECTIVE DEVICES

Control Relays

The basic control equipment in aircraft electrical circuits consists of switches and relays. Switches are used to open or to close circuits and may be either manually or mechanically operated. Relays are switches which are operated electrically, and are used to control one or more circuits by the action of a single circuit.

There are many types of relays. Those usually used in aircraft electrical and electronic circuits are based on the action of an electromagnet. The relays contain a coil to which voltage is applied. The resulting current in the coil produces a magnetic field which displaces a movable plunger, a hinged flange, or rotates a shaft. The moving part of the relay is called an ARMATURE. The movement of the armature is used to operate one or more sets of contacts which control the action of various electric circuits.

Several of the basic relay coil and armature arrangements employed in aircraft equipment are illustrated in figure 1–19.

In (A) of the figure, application of a d-c voltage to the coil magnetizes it and results in the downward movement of the hinged clapper armature. In the complete relay of which the coil and armature are parts, the armature motion is applied to the relay contacts. A spring opposes the motion of the clamper and restores it to the original position when the relay coil is de-energized, or disconnected from the source of control voltage.

The armature and coil of a plunger relay, also called a solenoid relay, are shown in (B) of the figure. When the coil is energized, the movable plunger is drawn into it. In the complete relay the movement of the plunger is transmitted to the associated relay contacts. In the rotary as-

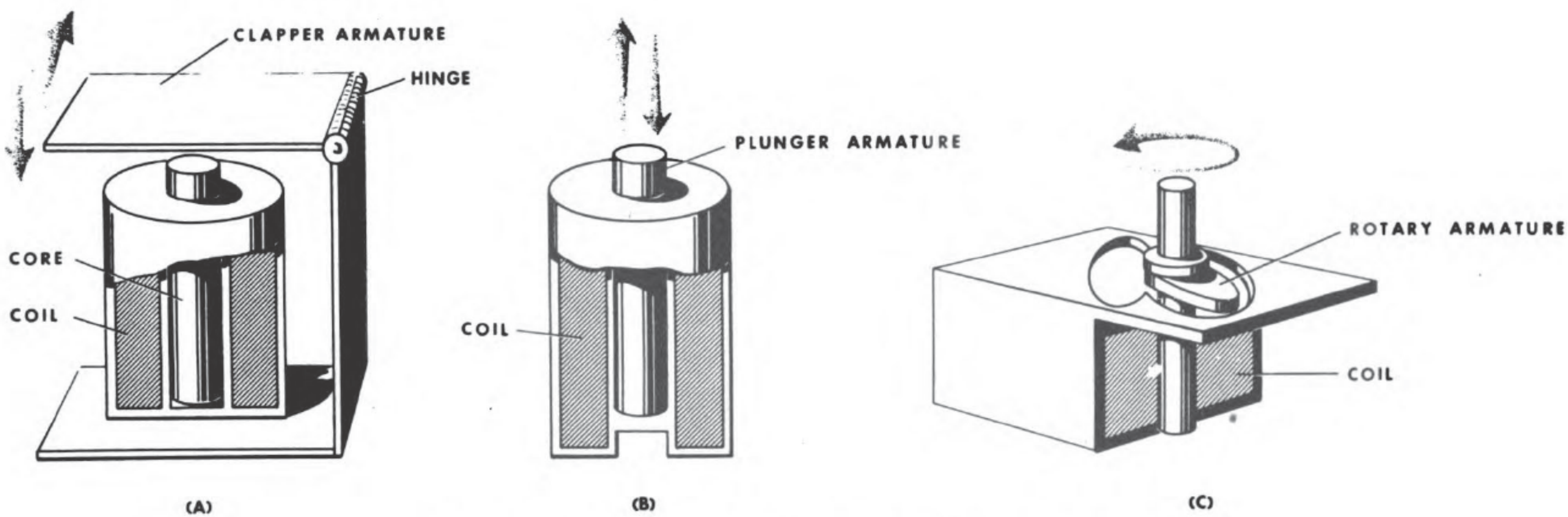


Figure 1-19.—Cutaway view of relay coils and armatures.

sembly shown in (C), the response of the armature to the magnetic force of the relay coil gives a rotary motion to the armature shaft to which the relay contacts are attached.

A method by which a plunger relay operates the attached contact is shown in (A) of figure 1–20. The single contact is open when no voltage is applied to the relay coil terminals. When the coil is energized, the resulting magnetism pulls the plunger against the lever pressing against the contact and forces it into the closed position. The contact shown is called a normally open contact. With no voltage on the relay coil it remains open and is closed only while the coil is magnetized. The normal condition of the relay occurs when no voltage is applied to the coil. In schematic drawings showing relays, the condition of the relay contacts is given in the normal condition, or with no voltage applied to the control coil.

The arrangement and number of associated contacts determine the sequence and number of switching operations which a relay can control. Many forms of control relays are manufactured and the number of contacts provided varies widely, ranging from one set to dozens of sets. The ordinary control relay is equipped with a combination of several kinds of contacts. These types of contacts are shown in figure 1–20.

The normally closed contact is shown in (B) of the figure. This contact remains closed until the coil is energized. The normally open contact appears in (C). In (D) the double

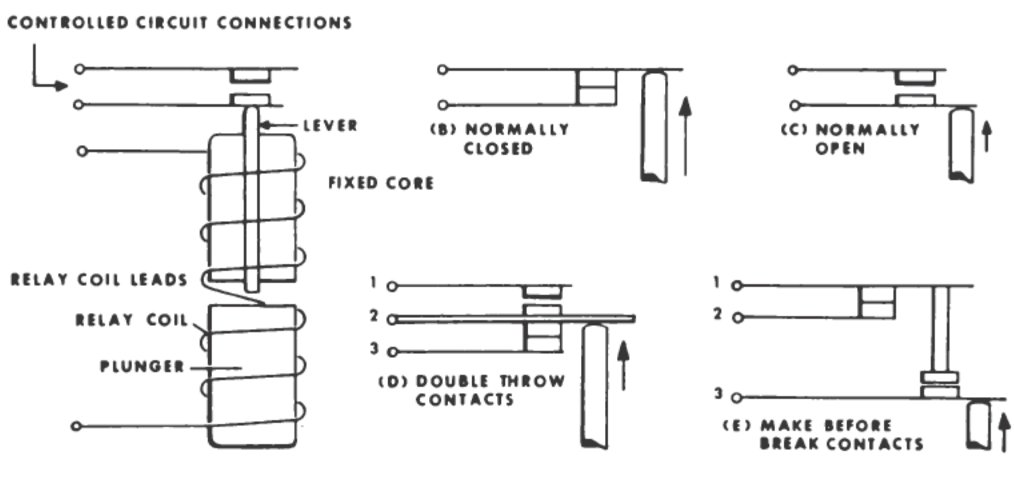


Figure 1–20.—Basic types of relay contacts.

throw contacts shown consist of two sets of contacts, one normally open and the other normally closed. After the circuit connected to terminals 2 and 3 is opened, the circuit attached to terminals 1 and 2 is closed. One set of contacts opens before the other closes. In (E) of the figure, the contacts attached to terminals 1 and 3 are closed before the normally closed contacts attached to terminals 1 and 2 are opened.

Generator Differential Control Relays

Differential relays are those which operate when the difference between two quantities such as current or voltage exceeds a given value. Relays of this type are used in aircraft generator circuits to control the application of engine-driven d-c generators to the d-c bus, to which the batteries are attached. The differential relay permits the application of the generator voltage to the d-c bus only if it is greater than the voltage of the bus. Otherwise current would flow from the bus through the generator in reverse direction, tending to discharge the batteries and perhaps damage the generator.

In aircraft applications, differential relays are used in connection with other relays. These include a main contactor, or relay, which operates a contact connecting the generator positive lead to the bus, a polarized voltage relay, and a reverse current winding. A unit consisting of these parts is called a generator differential control relay. An example is given in figure 1–21.

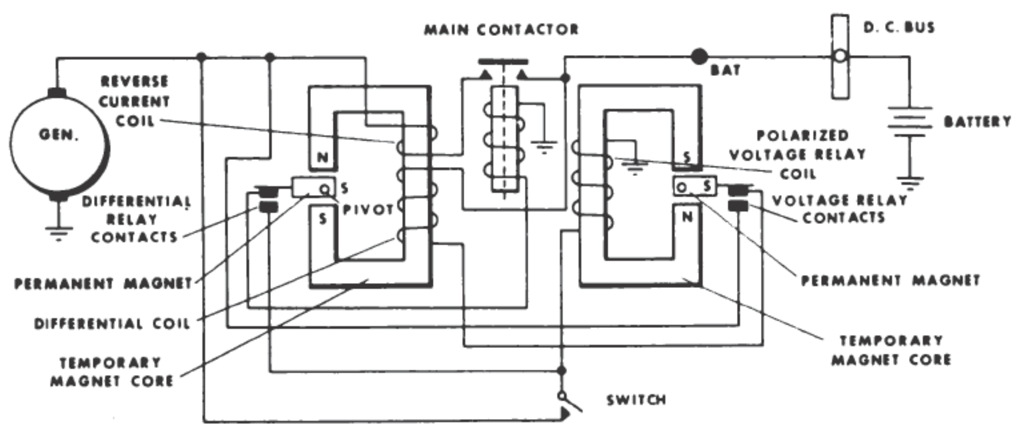


Figure 1–21.—Generator differential control relay.

The polarized differential relay (shown at the left of the figure) and the polarized voltage relay (shown at the right) contain normally open contacts which are closed by the motion of pivoted, permanent-magnet armatures. The motions of the armatures are governed by the direction of the magnetic fields in the iron cores on which the relay coils are wound. When the core magnetism is in the polarity indicated in the figure, the differential relay and polarized voltage relay contacts close.

The main contactor is a solenoid relay which applies the positive generator lead to the bus through the reverse current coil.

When the control panel switch is closed, the output of the generator is connected to the polarized voltage relay coil. If the generator voltage is 22 volts or greater, the magnetic action of the voltage coil acting on the temporary magnetic core of the voltage relay is great enough to swing the pivoted, permanent-magnet armature and close the contact. The contact closes the circuit which connects the differential relay coil between the d-c bus and the generator. If the generator voltage is from 0.35 to 0.65 volts greater than the bus voltage, the differential relay coil magnetizes the associated iron core material with the polarity shown in the figure, and trips the differential relay contact. This contact closes the circuit between the generator output and the coil of the main contactor, energizing the contactor coil and closing the normally open contact joining the generator to the bus.

During operation, if the generator voltage drops below the value of the bus voltage, current will flow from the bus to the generator and attempt to drive it as a motor. The reverse current flows through the reverse current winding. When its value reaches about 25 amperes, the resulting magnetic field in the core of the differential relay forces the pivoted permanent-magnet armature to open the differential relay contact. This opens the circuit containing the coil of the main contactor and the normally open contact, disconnecting the generator from the bus.

If the generator should build up with reversed polarity,

the polarized voltage relay prevents the application of the generator to the system. The reversed voltage, acting on the voltage coil, produces a magnetic field in the core of the polarized voltage relay which swings the pivoted, permanent-magnet armature in the direction which opens the contact. The open contact in the polarized voltage relay prevents the differential relay coil from being energized, and as a result the main contactor cannot be energized. This prevents application of the generator voltage to the d-c bus.

APPLICATION OF AUXILIARY POWER UNITS

In addition to its functions as a generator protective device, the differential control relay may also be used as a starting and protective relay for auxiliary power units. An auxiliary power unit contains a generator driven by a gasoline engine. The unit is used as a source of electrical energy for charging the aircraft batteries and for testing the electrical equipment. In some installations, the auxiliary power is supplied from an external unit mounted on a cart and attached to the aircraft electrical system through a power receptacle on the aircraft. In others, the auxiliary system is installed in the aircraft and is a part of the plane's electrical system. In the latter case, the differential control relay is often used as a starting contactor and reverse current relay. By means of a switching arrangement, the relay connects the aircraft storage batteries to the generator of the auxiliary power unit. The generator is run as a motor and cranks the gasoline engine. After the engine has started, it drives the generator which develops electrical power. The differential relay then serves as a reverse current relay and prevents further flow of reverse current from the batteries to the auxiliary generator.

GENERATOR OVERVOLTAGE AND FIELD CONTROL RELAYS

Overvoltage relays operate when the applied voltage reaches a preset value. These relays are used in aircraft

generator circuits to disconnect any generator from the system when its output voltage becomes excessive. Aircraft overvoltage relays must be constructed so that momentary surges of voltage, or transients, will not operate the contacts which disconnect the generator, but sustained overvoltage will do so. A type frequently used is a plunger relay containing a magnetic piston enclosed in a sealed, nonmagnetic cylinder which is located in the relay solenoid. The piston normally rests toward the end of the cylinder away from the relay armature and is held in position by a spring. Overvoltage applied to the relay coil causes the piston to move toward the armature, reducing the air gap in the magnetic circuit of the relay coil. When the air gap has been sufficiently reduced, the magnetic field becomes strong enough to displace the armature and operate the relay contacts, which disconnect the generator. Transient voltages, or surges, do not last long enough to move the piston into the position necessary to displace the armature. The spring replaces the piston in the position of maximum air gap when the relay is de-energized.

Field control relays are used to disconnect the shunt field of the generator when a fault or short circuit occurs in the associated system. The field relay disconnects the field winding of the generator, and reconnects it to a resistor, causing the voltage of the generator to drop, and the energy in the magnetic field of the generator winding to be dissipated in the resistor.

AIRCRAFT FUSES AND CIRCUIT BREAKERS

Fuses are used to protect electric circuits from the effects of excessive current caused by short circuits or abnormal operation of the equipment. A fuse consists of a suitably enclosed link which is designed to melt and to open the circuit when it carries overload current. This prevents damage to the equipment and the possibility of fire.

Fuses are made in two types: plug fuses and cartridge fuses. The type used in naval aircraft is the cartridge

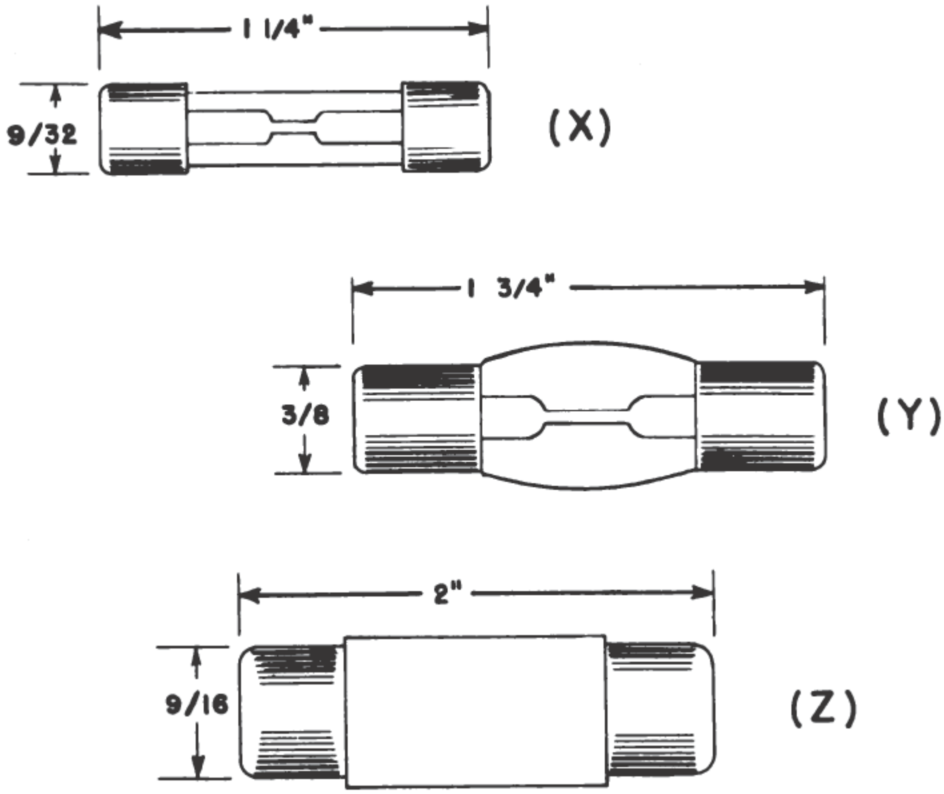


Figure 1–22.—Aircraft fuses. (X) Standard AG fuses; (Y) NAF 1034–6 fuse type 6HC; (Z) NAF 1034–9 fuse type 9HC.

fuse. A few of the more frequently used aircraft cartridge fuses are illustrated in figure 1–22.

Circuit Breakers

A circuit breaker is a protective device which is designed to open a circuit without injury to itself when excessive current flows in the circuit. The ratings of circuit breakers include a voltage rating and an interrupting current rating. The voltage rating refers to the maximum voltage of the circuit in which the device is to be used. The interrupting current rating gives the value of the current required to open the contacts of the breaker.

Circuit breakers may be operated by thermal switches, by the magnetic action of coils, or by a combination of both means. The contacts of the thermally operated circuit breaker open as a result of the heat produced by the overload current. This type is illustrated in figure 1–23.

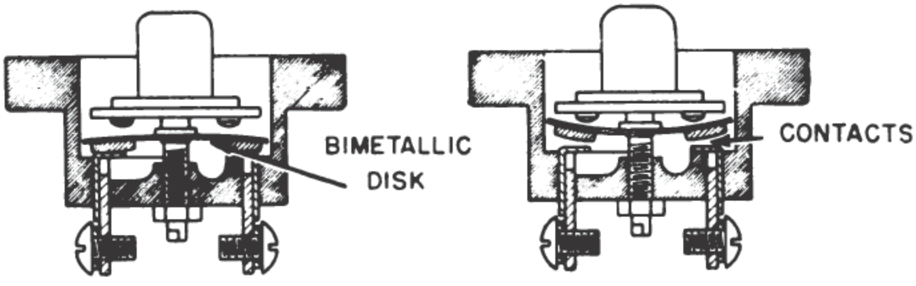


Figure 1–23.—Thermally operated circuit breaker.

The circuit breaker shown in figure 1–23 contains a conducting disk made of two layers of dissimilar metals. Two contacts are attached to the disk and close the circuit to be protected. When an overload current flows in the bimetallic disk, heat is produced and the two metals begin to expand. One metal is sensitive to heat and expands rapidly. The other is inert and holds back. These two opposing forces result in a snap action of the disk which bends into the position shown in the right-hand part of the figure. The contacts are opened and the overload current is interrupted. In the unit shown, a pushbutton is provided for resetting the contacts after they have been opened.

In thermal circuit breakers which are designed to interrupt low values of current, a resistance wire is inserted in series with the leads. Overload current raises the temperature of the wire and provides the heat required to snap open the bimetallic disk contacts.

Thermal circuit breakers have inverse time characteristics. This means that the time required to open the contacts depends on the amount of the overload current—the greater the overload, the shorter the time interval required to open the circuit.

Pushbutton circuit breakers, similar to the unit illustrated in figure 1–23, are reset by pressing a button. Once the contacts are closed they cannot be opened manually. In contrast to these, automatic-reset breakers are those which have no pushbutton and which reset themselves after

tripping. When the circuit opens and interrupts the current, the bimetallic disk cools and snaps the contacts back into the closed position, restoring the circuit to the operating condition. If the overload condition still exists, the breaker opens again.

A SWITCH-TYPE circuit breaker is equipped with a manually operated switch instead of a pushbutton and serves as a switching device as well as a protective element. The contacts of some switch-type circuit breakers are thermally operated, while others are magnetically controlled by means of a coil. Either automatic reset or manual reset may be employed. Those with manual reset are called INDICATING circuit breakers; that is, the position of the switch lever indicates whether the contacts are open or closed.

Circuit breakers may be either "trip-free" or "non-trip-free." The trip-free breaker opens when an overload occurs even if the reset switch is held in the closed position. The circuit cannot be closed if the overload condition exists. In the non-trip-free breaker, the contacts can be held closed if the overload condition exists.

In magnetic circuit breakers, the abnormally high currents resulting from short circuits energize an electromagnet which opens the contacts in the circuit it protects. The magnetic breaker has the disadvantage that it is difficult to set to trip at low values of current, in order to protect the equipment without also making the device inadequate to handle the high starting currents present in many of the components of aircraft systems.

The thermal circuit breaker has the advantage that its temperature characteristics are similar to those of the circuit it protects. It responds directly to the conditions which cause damage to the equipment.

QUIZ

1. The purpose of the voltage regulator is to compensate for
   a. variations in armature speed only
   b. load change only
   c. load and speed changes
   d. load and speed changes below normal rating of the generator

2. The voltage regulator accomplishes its job of regulation at higher than normal-range engine speed by
   a. decreasing resistance of the field circuit, thereby decreasing output E
   b. decreasing resistance of the field circuit, thereby increasing output E
   c. increasing resistance of the field circuit, thereby increasing output E
   d. increasing resistance of the field circuit, thereby decreasing output E

3. The reverse current relay is a protective device in that it prevents damage of the
   a. generator when generator voltage drops below bus line voltage
   b. battery when generator is producing excessively high voltage
   c. generator when generator is producing excessively high voltage
   d. generator due to overload on system

4. The current capacity of a lead-acid battery depends on
   a. total plate surface area per cell
   b. total number of plates per cell
   c. total number of cells
   d. total number of plates per cell plus total number of cells

5. The sources of power in an aircraft are connected through switches and control equipment to
   a. individual buses
   b. a main bus system
   c. junction boxes
   d. the distribution panel

6. The purpose of the commutating poles in the engine-driven d–c generator is to
   a. oppose field distortion
   b. control generator output
   c. add to field strength
   d. minimize brush sparking

7. While using two generators, A and B, and an equalizer circuit, a condition occurs in which generator A is furnishing more current than generator B. The equalizer overcomes this condition by
   a. increasing the field resistance of both A and B
   b. increasing the field resistance of A, and decreasing the field resistance of B
   c. decreasing the field resistance of both A and B
   d. decreasing the field resistance of A, and increasing the field resistance of B

8. The use of engine-driven a-c generators reduces or eliminates the use of
   a. d-c generators
   b. inverters
   c. voltage regulators
   d. dynamotors

9. How many stator windings are employed in a 3-phase a-c generator?
   a. 6
   b. 3
   c. 12
   d. 9

10. How is the output frequency of an engine-driven a-c generator controlled?
    a. By means of a constant-speed drive unit
    b. By varying the number of poles
    c. By controlling the speed of the aircraft engine
    d. By the use of a frequency dividing network

11. Many aircraft 3-phase systems employ alternators with wye-connected stator windings in which the neutral connection of each wye is grounded. How many wires are usually found in such a system?
    a. 3
    b. 4
    c. 5
    d. 6

12. What is the functional purpose of the d-c exciter in an alternator?
    a. To excite the alternator rotor
    b. To excite the alternator stator
    c. To determine frequency output
    d. To furnish driving e. m. f.

13. In an alternator, which is the purpose of the stabilizing transformer?
    a. To stabilize d-c exciter speed
    b. To compensate for speed changes
    c. To compensate for sudden load changes
    d. To control stator induction
14. The active materials used on the positive and negative plates of the lead-acid battery are
    a. lead acid and lead dioxide
    b. lead peroxide and lead dioxide
    c. spongy lead and lead peroxide
    d. spongy lead and lead acid
15. The thin porous sheets used as separators in the lead-acid battery serve the purpose of
    a. controlling electrolyte flow
    b. determining battery capacity
    c. preventing plates from shorting together
    d. supporting the plate chemicals
16. During discharge of the lead-acid battery, the plate chemicals are converted into
    a. lead acid
    b. water
    c. lead oxide
    d. lead sulfate
17. A specific gravity of 1.240 would determine that the cell is
    a. fully charged
    b. ⅔ charged
    c. ⅓ charged
    d. fully discharged
18. Lead-acid batteries are rated in
    a. volts
    b. amperes
    c. ampere hours
    d. specific gravity
19. The explosive gas created during charging of a lead-acid battery is
    a. oxygen
    b. hydrogen
    c. sulphuric
    d. lewisite
20. A lead-acid battery in storage, at a temperature of less than 80 degrees F., must be recharged at intervals of
    a. 1 week
    b. 2 weeks
    c. 1 month
    d. 2 months

21. A dynamotor is used for converting
    a. low d-c voltage to high d-c voltage
    b. low a-c voltage to high d-c voltage
    c. high d-c voltage to low d-c voltage
    d. high a-c voltage to low d-c voltage
22. The basic control equipment in aircraft electrical systems consists of
    a. remote controls
    b. switches and fuses
    c. relays and switches
    d. fuses and circuit breakers
23. Which of the relays listed below is a differential control relay?
    a. Battery relay
    b. Reverse current relay
    c. Master radio relay
    d. Inverter relay
24. A circuit breaker which is activated by a bimetallic disk is said to have which of the following actions?
    a. Spring action
    b. Thermal action
    c. Resetting action
    d. Voltage action

CHAPTER 2

INTRODUCTION TO AIRBORNE RADAR AND LORAN

Radar increases the effectiveness of naval aircraft by adding new powers and capabilities to the human senses. It is unhampered by the ordinary obstacles to unaided vision such as darkness, fog, haze, and smoke. Radar reveals the presence and location of certain kinds of objects situated far beyond the range of normal vision, indicating their distance and bearing directly and with a high degree of accuracy. In short, the airborne radar set provides the pilot and operator with a pair of radio eyes that can pierce the surrounding darkness or overcast and "see" ships, land areas, cities, clouds, and other aircraft.

In some respects, radar detection is inferior to normal vision. Radar presentations reveal almost no detail and show only the general outlines of objects. The ability of radar to distinguish between various types of objects is limited, and it presents unwanted echoes from sea waves and land (called "clutter") as readily as from important targets. It is also subject to willful interference or jamming by the enemy. Radar is most successful in revealing isolated objects located in a background without numerous details. Good target subjects are ships at sea, aircraft in flight, and coastlines. In the map-like radar presentation of the PPI (plan position indicator) screen often employed in airborne search units, many details of complicated targets such as cities are clearly shown, but the presentation is considerably

poorer in detail than an aerial photograph taken under conditions of good visibility.

While radar is a powerful aid to the aircraft, the aircraft in turn increases the powers of radar by supplying it with an elevated platform from which its effective range in detecting objects is greatly extended. The application of radar to airborne operations has been most successful in military aircraft and is now an indispensable part of the plane. In naval aircraft, the general purposes served by radar are the following:

1. Search and reconnaissance.
2. All-weather fighter or intercept operation.
3. Identification of friend or foe.
4. Navigation and beaconry.
5. Bombing, rocketry, and fire control.
6. Aircraft early warning or relay systems.
7. Antisubmarine warfare.
8. Aerial minelaying.

In its basic operation radar works on the echo principle. Radio waves are sent out from a powerful transmitter. A very small amount of the radiated energy is reflected from objects in the range of the set and returned to the radar receiver which in most cases is located at the transmitting site. After passing through the various stages of the receiver, the reflected signals are either converted into visual displays or some property of the signals is measured directly. The final presentation of the echo is used to reveal information concerning the object causing the reflection.

The waves emitted by the transmitter may be c-w signals, frequency-modulated signals or regularly recurring pulses of high power. One of these types, pulse radar, has been developed to a far greater extent than all others. Most of the equipment designed for the purposes mentioned above are pulse radar devices, although one very important unit, the absolute altimeter, is based on frequency-modulation operation in one of its versions.

In pulse radar sets, the transmitter radiates radio waves in brief bursts of extremely high power. The time duration of the emitted pulse is very short compared with the interval

between bursts. During these intervals the transmitter is idle and the receiver accepts reflections soon after the pulse leaves the transmitter. Echoes from more distant objects return at a slightly later time. After a length of time sufficient to allow echoes to return from the most distant objects in the range covered, the transmitter is turned on for another pulse and the operation is repeated.

This general method of operation is employed in airborne radar sets used for search and reconnaissance.

AIRBORNE SEARCH RADAR

Search radar, the basic type used in almost all radar-equipped planes, shows the range and azimuth of targets such as ships, islands, coastlines, and other aircraft within the reach of its beam. It is frequently used to detect enemy ships; and by means of associated bombing equipment, is employed in making blind bombing runs on them. Search radar is an effective aid to air navigation since it exhibits land masses and storm clouds on the radar screen and is equipped to display coded signals from ground-based radar beacon stations. It works in conjunction with the IFF system which identifies the ships and aircraft detected as friendly or hostile by means of coded replies.

Range measurement.—The measurement of range, or distance, by radar methods is based on the fact that radiated r-f energy travels through space at a constant velocity, the speed of light, which is about 186,300 statute miles per second. Expressed in feet rather than miles, this speed is 983,664,000 feet per second, (or about 984 feet per microsecond).

Unless otherwise specified, Navy search radar sets are calibrated in nautical miles of range. One nautical mile is equal to 6,076.10333 feet. If this number of feet is divided by the number of feet travelled by a radar pulse in one microsecond (983.664), the quotient is 6.177, or approximately 6.18 microseconds per nautical mile. Hence, the radar pulse covers one nautical mile in 6.18 microseconds.

The radar set determines range by measuring the elapsed

time during which the emitted pulse travels to the target and returns. Since two-way travel is involved, a total time of 12.36 microseconds must elapse between the start of the pulse and its return, provided the target is at a range of one nautical mile. The range in nautical miles of any object can then be found by measuring the time elapsing during a round trip of the radar pulse (in microseconds) and dividing this quantity by 12.36. In equation form, this is

$$\text{Range}=\frac{\text{Elapsed time.}}{12.36}$$

In range measurements based on this relation, most systems employ a cathode-ray tube indicator. A time scale is provided by sweeping the electron beam across the screen by means of a linearly rising voltage resulting in a visible trace line on which equal distances correspond to equal time intervals. The echo signals from targets are then superimposed on the time scale in such a way that their distances from the transmitter are revealed. Figure 2–1 illustrates range measurement by means of a basic type of indicator, the A-scope.

The system is pulsed many times each second and a time base, or sweep, is retraced with each pulse with the result that the moving spot of light in the cathode-ray tube appears as a continuous bright line. The radar data are presented as vertical deflections (pips) of the moving beam.

The time scale is provided by the linear sweep voltage which controls the horizontal motion of the electron beam in the indicator tube. Assume that the beam travels five inches from left to right across the screen in 123.6 microseconds. The five-inch trace then represents 10 nautical miles of radar range, since 12.36 microseconds correspond to 1 nautical mile of two-way travel. (Each half inch of trace represents 1 nautical mile of range.)

The figure illustrates the action occurring during the radiation of a single pulse. In (A) a 1-microsecond pulse leaves the transmitter and is represented on the indicator

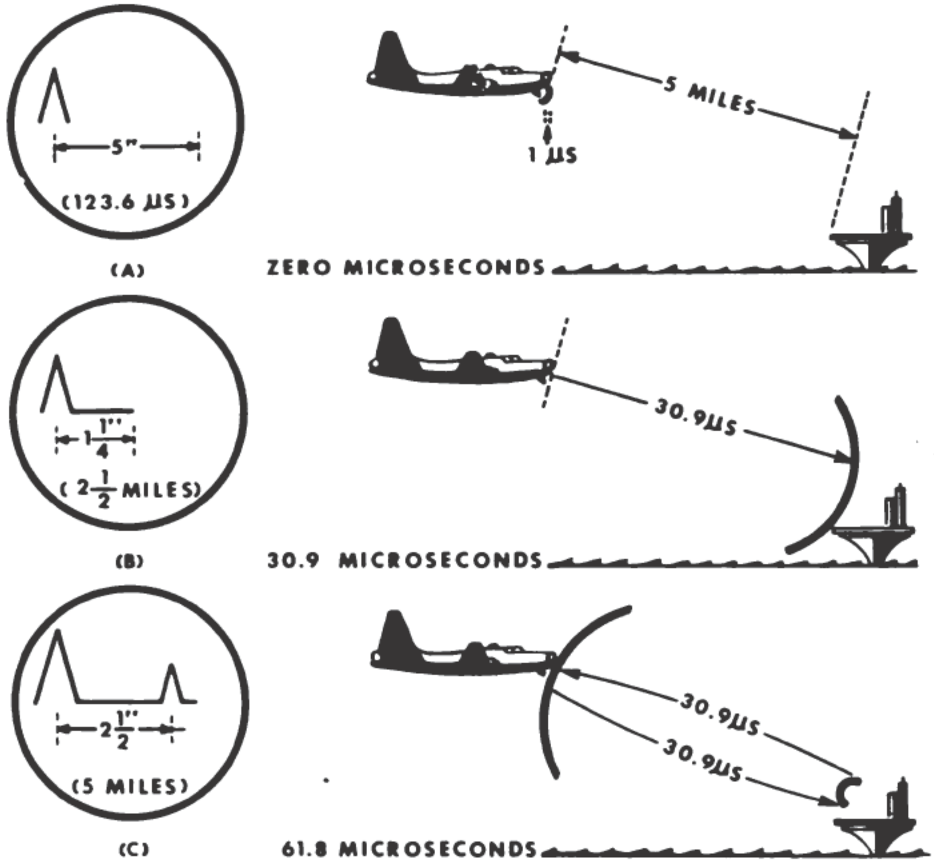


Figure 2-1.—Range measurement with cathode-ray tube.

by a large vertical deflection, whose position on the display marks the zero range point. In (B) the outgoing pulse strikes a target five miles distant from the transmitter, and a small amount of the energy is reflected. This occurs 30.9 microseconds after the start of the pulse; and in this time, the beam in the indicator tube has reached a point 1¼ inches to the right of the zero range pip on the screen. In (C) a small part of the echo from the target has returned to the antenna and enters the receiver 61.8 microseconds after the start of the pulse. The receiver applies an impulse resulting from the reflected signal, causing a small deflection at a point 2½ inches to the right of the starting point of the trace. This pip indicates the presence of an object 5 miles away.

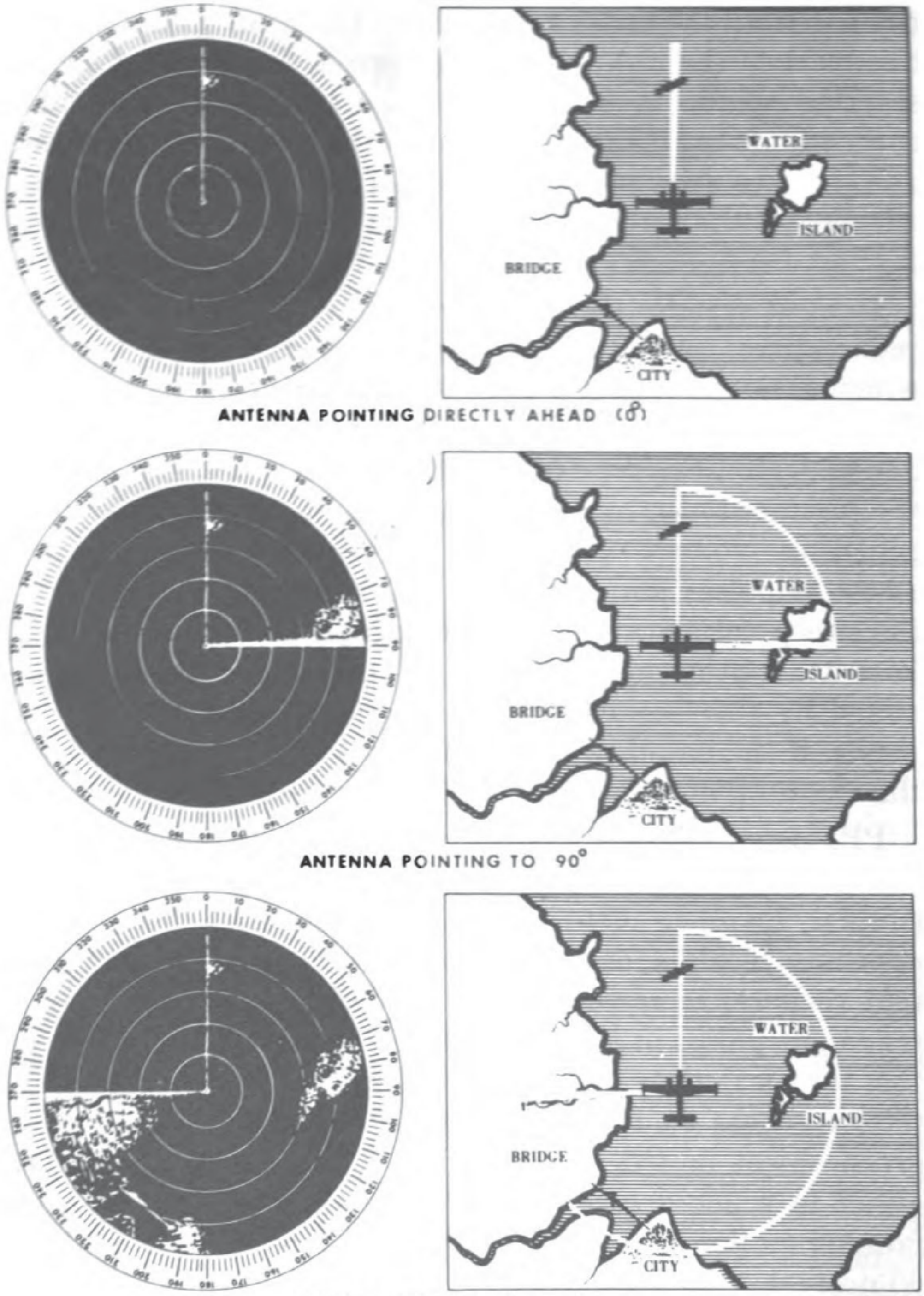
When 123.6 microseconds have elapsed, the greater portion of the outgoing pulse has reached a point in space 20 miles

distant from the radar set. The beam in the indicator tube has reached the right side of the screen, five inches from the starting point. A blanking voltage applied to the grid of the cathode-ray tube extinguishes the beam and deflecting voltages are applied which will start the next sweep at the left side of the screen. The system is then ready to repeat the same action with another pulse.

In most systems the target range is read directly from the radar screen by the use of range markers. These are lines which divide the screen into regular intervals representing distance, appearing as vertical lines or as concentric circles depending on the type of presentation in use. The markers are produced electronically by means of an oscillator which generates voltage variations at regular time intervals. These impulses are applied to the indicator in addition to the sweep voltage and the target signals and cause the range lines to appear on the screen. The range scale is determined by the frequency of the marker generator. For example, if the impulses are applied every 12.36 microseconds, the resulting markers divide the screen into 1-mile intervals.

PPI PRESENTATION.—The basic airborne radar presentation is the PPI (plan position indicator) which presents a circular, map-like picture of the area scanned. The targets appear as bright spots at positions on the screen which represent their range and bearing. A highly directional antenna sends out pulses in a narrow beam and receives echoes from the targets. Only the targets that are within the beam return echoes so that the antenna must be pointing at a given object in order to detect it. The antenna is moved either in a 360-degree circle around the plane or else in a fanning motion covering a particular sector, usually of about 60 degrees.

The basic 360-degree scan used with the PPI indicator is illustrated in figure 2–2. Each time the transmitter sends out a pulse, the electron beam in the indicator tube sweeps from the center of the tube outward to a point on the edge which depends on the direction in which the antenna is pointing. If an echo is returned, a bright spot appears



ANTENNA POINTING DIRECTLY AHEAD (0°)

ANTENNA POINTING TO 90°

ANTENNA POINTING TO 270°

Figure 2-2.—PPI presentation.

which is located at a distance from the screen center proportional to the range of the target.

Currents in the deflection coils of the CRT indicator rotate the trace around a fixed pivot point at the center of the screen in synchronism with the antenna, and the bearing of the target is indicated by the radial position of the time trace line.

In using the PPI scope to find the relative bearings of targets, the top of the screen corresponds to a dead-ahead position of the antenna. The outer edge of the screen is equivalent to the horizon. In some indicators, a graduated azimuth ring is fitted at the outer edge of the screen and a transparent mask inscribed with a line is fitted over the tube face. The relative bearing of a given target is read on the graduated azimuth ring. It is the value under the line on the movable mask when this line has been set so as to bisect the target image on the screen.

In many search radar sets, true bearing operation is also provided in which the top of the indicator display is oriented with true north by signals supplied by the flux gate compass of the airplane. The indicator remains in this position regardless of the heading of the plane and the PPI scope is read as a map.

In operational equipment, the PPI presentation is used in many forms. These include open center display, target discrimination display, sector scan, true bearing indication, and altitude delay operation. These types of display are illustrated in chapter 6 which is concerned with the AN/APS–33 search set.

Components of the system.—Search radar equipments vary considerably in detail depending on the amount of information and the accuracy of the data which they are required to supply. However, all systems of search radar using pulse modulation work on essentially the same principles, and their basic operations depend on the same kinds of major components. A basic search system is shown in simplified block diagram form in figure 2–3.

The synchronizer is the timing unit. It produces trigger

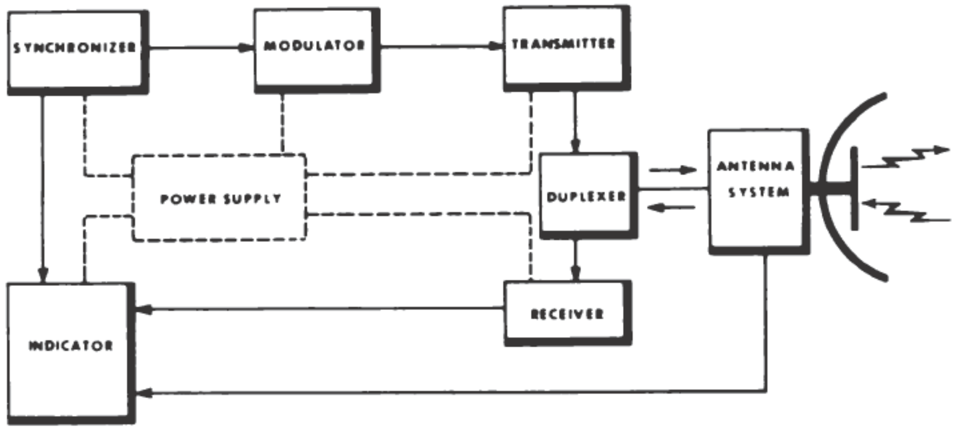


Figure 2–3.—Block diagram of basic airborne radar system.

pulses which control and coordinate the circuits of the system so that each operates at the correct time. In most systems it governs the number of pulses the transmitter produces in each second (called the pulse repetition frequency or pulse recurrence rate). It coordinates the sweep voltage in the indicator tube with the firing of the transmitter, and contains provisions for delaying the beginning of the sweep to give special types of display (such as open center and target discrimination operation). The synchronizer contains the circuits which generate the range marker voltages and the trigger pulses which unblank the indicator tube when the trace starts to appear on the screen. Pulses supplied by the synchronizer are also used to control indirectly the associated equipment used with the search system.

The MODULATOR controls the operation of the transmitter by applying high-voltage pulses of rectangular shape. The pulses are usually supplied by charging a section of artificial transmission line in the modulator to a high potential during the interval between pulses. The modulator action begins when a trigger pulse from the synchronizer is applied to a switch tube in the modulator unit. The switch tube terminates the artificial line and causes it to discharge a rectangular pulse through the transmitter tube. The length of time during which energy is transmitted is called the pulse width, the value of which is determined by the components of the transmission line. In airborne applications, the modulator

unit is usually enclosed in a container and operated under a constant pressure to prevent high-voltage arcing.

The TRANSMITTER consists principally of a magnetron which oscillates at extremely high frequency throughout the interval of the pulse applied by the modulator. The magnetron produces the electromagnetic energy which is radiated from the antenna into space. Airborne search radar sets employ microwaves, a typical value of wavelength being about 3 centimeters. The output of the magnetron is conducted to the antenna through waveguide transmission lines consisting of hollow metal tubing.

The ANTENNA SYSTEM has two general purposes. It radiates pulses of microwave energy developed by the magnetron, confining the waves into a narrow beam. In addition it receives the echo signals from targets and applies them to the receiver. The antenna system consists of waveguides, switching tubes, a reflector for beaming the radiated energy, a mechanism for rotating the reflector during operation, and servo units which coordinate the position of the indicator sweep with the position of the antenna reflector.

Since the same antenna is used both for transmitting and receiving, it is necessary to switch it alternately from one component to another. This action is accomplished by the DUPLEXER which consists principally of the TR (transmit-receive) tube and the ATR (anti-TR) tube. These are resonant cavities containing gas at a low pressure. Arc-discharges take place in the cavities when the transmitter pulse is applied to the waveguide containing them. The TR tube prevents the transmitted pulse from entering the receiver and damaging the sensitive crystal mixer. When the transmitter is idle, both tubes are de-ionized, and the ATR tube serves to prevent reflected echoes from entering the magnetron, allowing them to flow into the receiver.

The RECEIVER is an extremely sensitive superheterodyne containing circuits with bandwidths capable of passing pulses of the type emitted by the transmitter. It is important that the receiver generate as little local noise voltage as possible to avoid masking weak echo pulses.

The signals from the antenna are usually applied first to a crystal mixer where they are mixed with the output of the local oscillator, a reflex klystron tube. The i-f output resulting from the mixing process is then amplified in a number of i-f stages. In aircraft receivers the intermediate-frequency value is between 15 and 60 megacycles. A video detector converts the i-f energy into video pulses. After passing through one or more stages of video amplification the signals are applied to the cathode-ray indicator.

Aircraft radar receivers employ automatic frequency control to keep the receiver intermediate frequency from drifting. A typical method is as follows: A portion of the transmitter output is applied to a separate mixer, called the AFC mixer, to which some of the output from the klystron local oscillator is also applied. The AFC mixer develops the difference frequency of the two and applies this signal to a discriminator circuit. The discriminator output voltage is zero when the correct intermediate frequency is produced. But if the receiver local oscillator is not on the correct frequency, the discriminator produces a d-c voltage which is positive or negative depending on whether the local oscillator frequency is too high or too low. The d-c output of the discriminator is then applied to the repeller plate of the klystron local oscillator. This corrects the klystron frequency until it differs from the frequency of the outgoing pulse by the proper amount.

The INDICATOR accepts the radar data such as video pulses, the range marker voltages, and sawtooth timing waves and presents them in a visual display on the screen of a cathode-ray tube. The entire assembly contains the cathode-ray tube and various electronic circuits necessary for presenting the desired information on the screen. These circuits include video amplifiers, diode clamping tubes, and the controls for adjusting the brilliance of the visual pattern.

Two general types of presentation are used in aircraft radar indicators, the deflection and the intensity displays. In the deflection method, the video pulse causes a momentary deflection of the cathode-ray electron beam and produces a

pip in the trace to indicate a target echo. In the intensity method, the video signal is applied to an element of the CRT which controls the intensity of the electron beam, and the resulting target image is a bright spot of light. The A-scope is an example of the deflection method and the PPI is a typical intensity presentation.

Sawtooth timing waves of voltage or current are applied to the deflection circuits of the CRT to produce the time trace or sweep in the pattern. The synchronizing pulse which triggers the modulator and transmitter also serves to coordinate the start of the sweep with the action of the transmitter to make range measurements possible. Target bearing in most displays is indicated by synchronizing the position of the sweep line on the screen with the position of the antenna.

In addition to video pulses, range marker pips, and sweep voltages, a square wave pulse is applied to the indicator tube which blanks the beam between sweeps so that retrace lines do not appear on the screen.

The POWER SUPPLY equipment converts low-voltage power from the aircraft electrical system into voltages and currents suitable for the electronic circuits of the radar set. In the block diagram in figure 2–3, the power supply is represented as a single block. Sometimes for convenience, the radar system derives power from two or more separate rectifier units. This arrangement is used because the components are located in different places in the plane and have widely different power requirements.

Several values of voltage are required. These include high-voltage d. c. ranging from 1,000 to 15,000 volts, medium-voltage d. c. from 150 to 600 volts, and low-voltage power, either a-c or d-c, for operating the filaments of the tubes. The rectifiers which supply the d-c values derive primary input power through transformers from one of the following alternating-current sources:

1. Motor alternators driven by the 27.5-volt, d-c electrical system in the plane.
2. Engine-driven generators which produce two outputs,

27.5-volt d. c. and 115-volt variable-frequency alternating current.

3. Three-phase a-c systems (in large planes) with both 200-volt and 115-volt outputs.

The frequency developed by engine-driven motor alternators changes with engine speed, and the rectifier units which operate with this source of primary power must be designed to perform satisfactorily under conditions of varying frequency. Some radar units such as computers and synchros require a fixed-frequency a-c source, and small inverters are usually provided to supply them with power.

The a-c machines which supply primary power for the radar equipment are usually equipped with voltage regulators, either electronic or carbon pile. These keep the output voltage reasonably constant under changes in load current, engine speed, and varying conditions of operation.

ALL-WEATHER ATTACK RADAR

Special types of radar are used in all-weather fighters and attack bombers which are extensions of the basic search equipment. A typical installation of this kind performs the following functions: Detection and location of aircraft; gun aim indication for the firing of fixed guns; detection and location of ships and other objects on the surface of the sea; mapping of land-water contours as a navigational aid; and detection (and location) of beacon stations for the purpose of homing and navigation.

All-weather fighter radar is similar to general search equipment in its basic principles of operation and in the types of major components used. Since this equipment is used in tactical actions against enemy aircraft, it employs types of presentation which show the altitude of the target with respect to the fighter plane. A high value of PRF (pulse repetition frequency) is used; and special devices for suppressing clutter, unwanted echoes from sea or land, are important parts of the equipment. The minimum range at which targets can be detected must necessarily be of a low

value in this type of radar, with typical values ranging from 100 to 150 yards.

The usual all-weather fighter equipment differs from other types in the variety and kinds of scanning patterns provided. The antenna assembly is designed to make several sorts of motion and can sweep the radar beam over the search area in a number of different ways. These types of scanning patterns include search, intercept, acquisition, and aim scans.

SEARCH SCAN.—This operation is employed in detecting and locating land, sea, or air targets, and in mapping contours at various ranges. It is not used for location of aircraft at large angles of elevation.

The radar beam is sometimes distorted by a beam deflector at the antenna to give a downward coverage, and the resulting pattern is swept in sectors of either wide or narrow angle, as shown in figure 2–4.

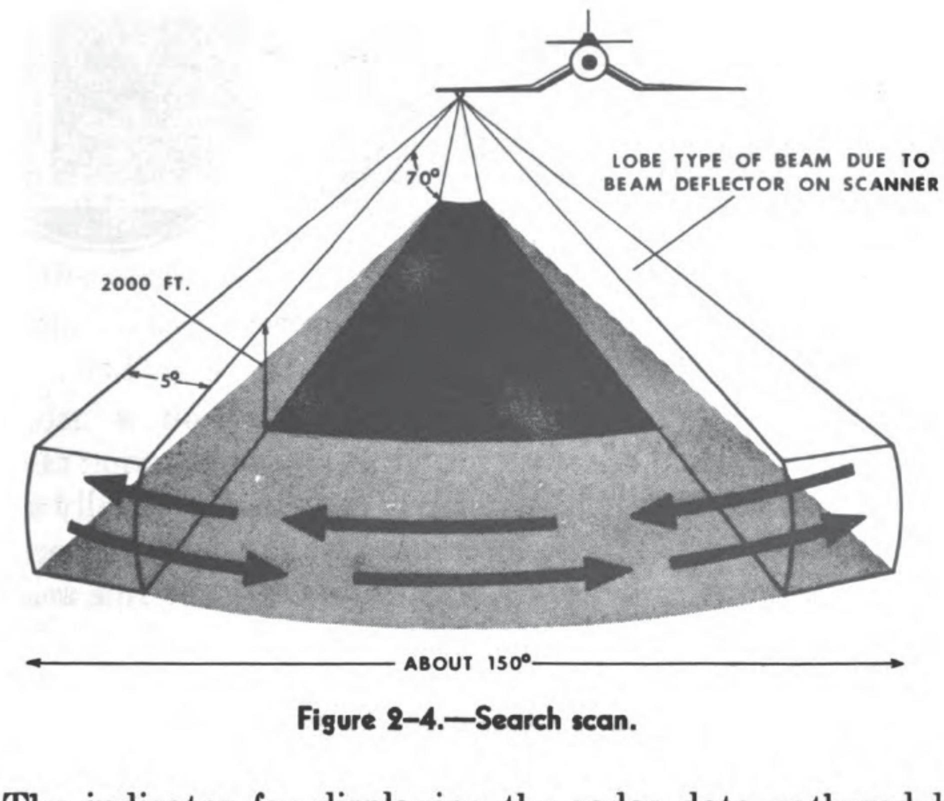


Figure 2–4.—Search scan.

The indicator for displaying the radar data gathered by this scan in many installations is the B-type of presentation. This is a square, map-like display in which the horizontal position of the indicator trace is synchronized with the direc-

tion in which the antenna points. The position of the target image on the scope measured horizontally from the vertical center line indicates the bearing of the target. A vertical sweep of the cathode-ray beam occurs with each pulse; hence, the position of the image measured vertically from the lower edge of the screen indicates the range. The appearance of the B-scope and the relation of the trace to the antenna direction is shown in figure 2–5.

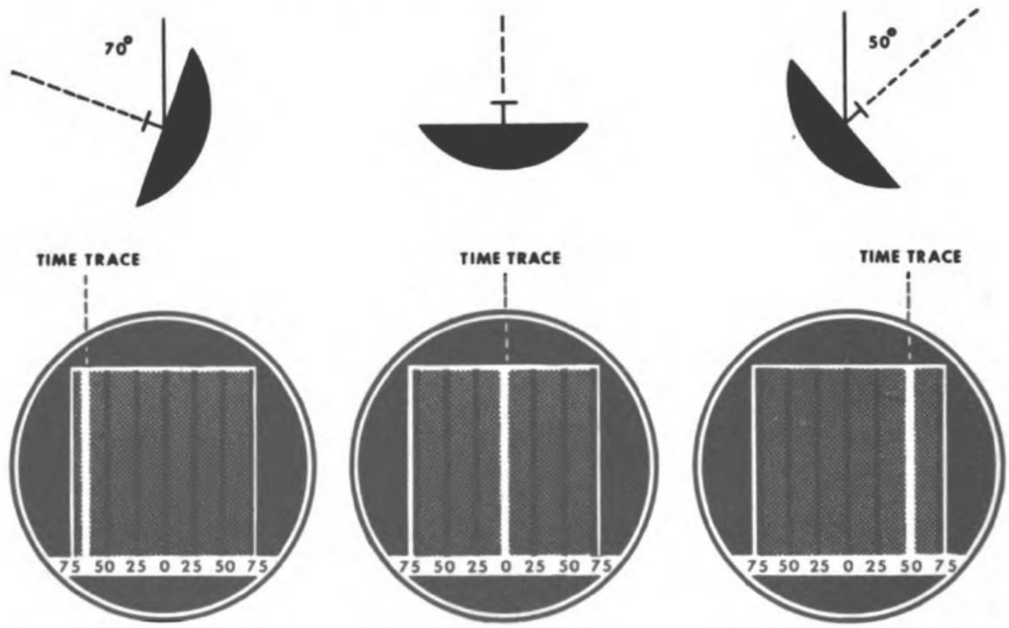


Figure 2–5.—Type B presentation.

Intercept operation.—Intercept operation is used for detecting and locating enemy aircraft and for making tactical approaches on them. The range of detection is usually about 20 miles or less. In some radar systems, this operation involves a complex type of scan in which the antenna scanner revolves rapidly in a way that causes the radar beam to search a solid angle by tracing out a spiral. After an increasing spiral has been described and the diameter reaches a maximum value, the beam then traces another spiral path which diminishes to the center. Two values of search angle are usually provided as shown in figure 2–6. The radar beam in spiral scan is in the form of a narrow ray about 5 degrees in diameter.

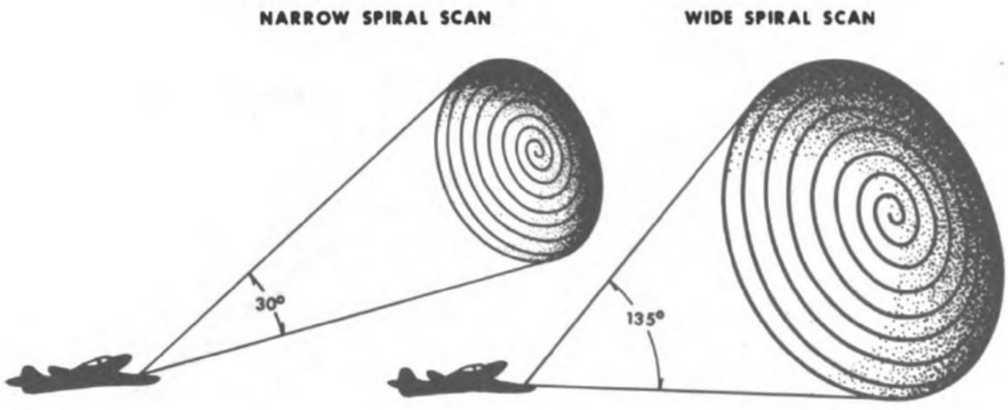


Figure 2-6.—Space diagram of spiral scans.

The information gathered by spiral scanning is often presented on a modified B-scope called a "double-dot" display. The screen shows azimuth, range, and elevation of the target aircraft. Two bright dots appear for each target. One of the dots is the usual range-azimuth image which appears on the B-scope during search operation. About one-eighth inch to the right of the target dot is a second dot which indicates the relative elevation of the target. The elevation dot is alongside the target dot when the target is in the line of flight of the observer. It is higher or lower on the screen when the target is above or below the observer.

In the newer intercept radars, the type of antenna scan used is called a "Palmer scan" because it combines the motion of a small, rapidly spinning cone along with a slower left-right motion, and therefore resembles the old circular type of penmanship exercise popularized by Palmer many years ago. The advantage of this type of scan over the spiral is that the azimuth and elevation coverage can be varied independently, and a wider angle in azimuth than in elevation is usually desired. The usual type of display is a standard B-scope with some device to display antenna tilt for elevation information.

ACQUISITION SCAN.—This operation is used for the detection and location of aircraft targets at greater ranges than can be expected in search or intercept operations. A typical scanning pattern for older radars is shown in figure 2-7 in

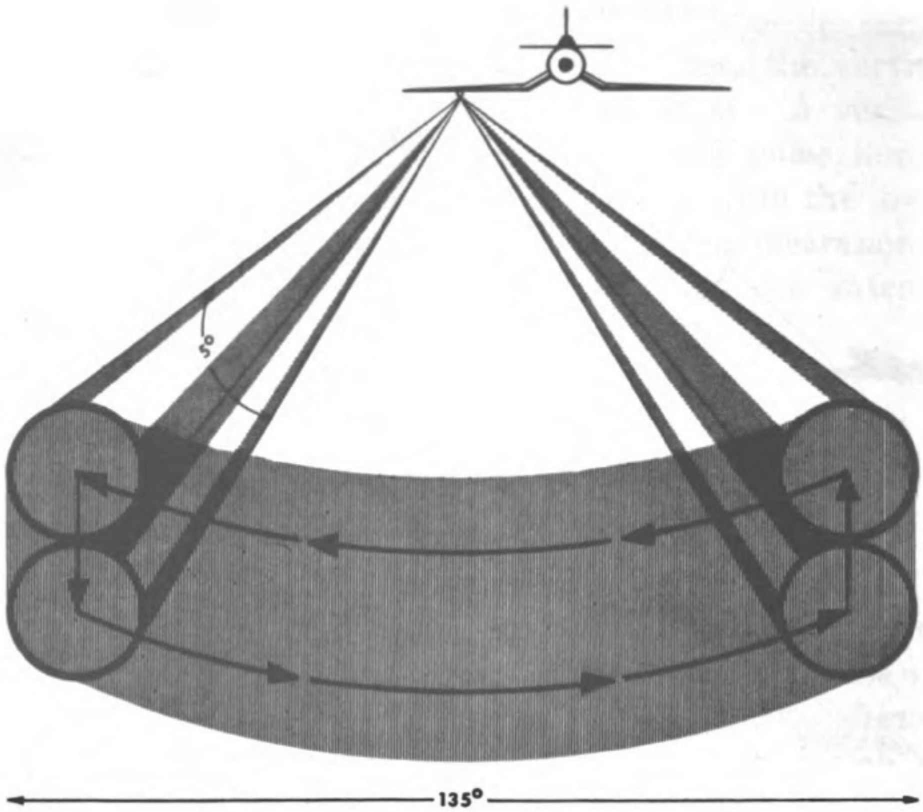


Figure 2-7.—Acquisition scan.

which the antenna is moved from side to side, directing a narrow beam in a sector of about 135 degrees. At the two extremes of the sweep, the beam is displaced approximately 5 degrees in the vertical plane so that the center line of the ray traces a rectangle.

Since the radiated energy is concentrated into a narrow ray and is not distorted or fanned downward, the intercepted targets within the field of view return strong echo signals. Targets which are not discernible in search operation can be detected with acquisition scan.

GUN AIM PRESENTATION.—Several types of gun aim displays are used in all-weather fighter radar equipment. One of these, the G presentation is shown in figure 2-8. The scope is used for aiming the plane's fixed guns and has an appearance similar to an optical gunsight.

On the G-scope, target azimuth is indicated by the image position along the horizontal axis, and elevation is represented on the vertical axis. The target appears as a

bright spot with wings. The span of the wings represents the range. With the dot centered at the intersection of the inscribed cross hairs, and the wings just touching the vertical marks, the target is at the point of convergence of fire, usually about 250 yards. If the wings are of lesser width, the distance is beyond the gun-convergence range. When the wingspan is greater than the distance between the lines, the enemy plane is closer than the open-fire point. The position of the winged dot up or down, right or left, gives the position of the target relative to the fighter plane.

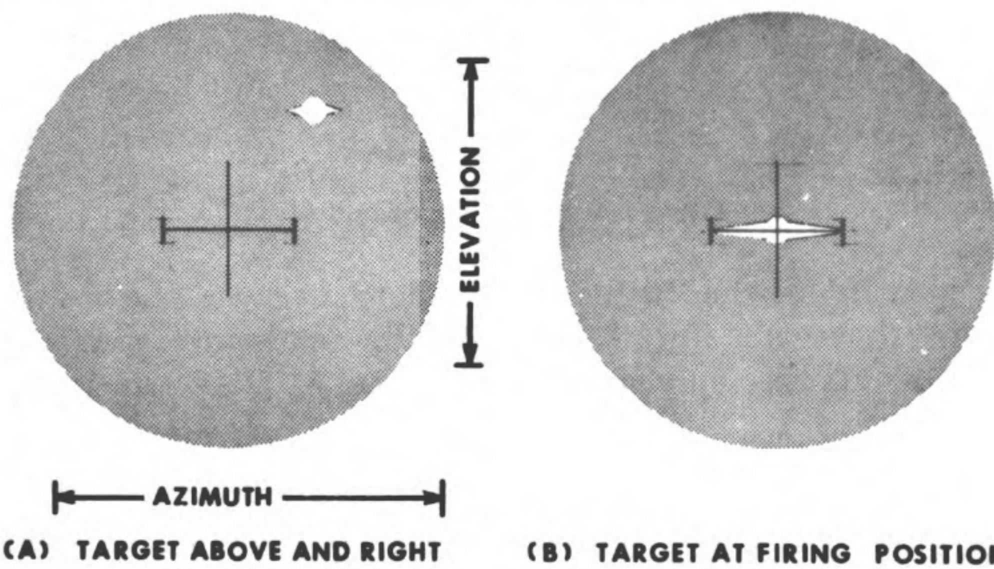


Figure 2-8.—Type-G display, or gun aim presentation.

A conical antenna scan is used with this type of presentation. The antenna reflector is rotated about a center point so that the radiated beam searches a cone of space forward of the aircraft. The diameter of the cone is twice the beam diameter, and the angle at the apex may be 8 to 12 degrees. Another and more popular variation is to show the range on a separate line or trace on the same display, retaining the dot for the up-down, right-left information.

IDENTIFICATION, FRIEND OR FOE (IFF)

The primary purpose of an IFF system is to provide an accurate and rapid means of determining the friendly or enemy character of objects detected by radar. Some means

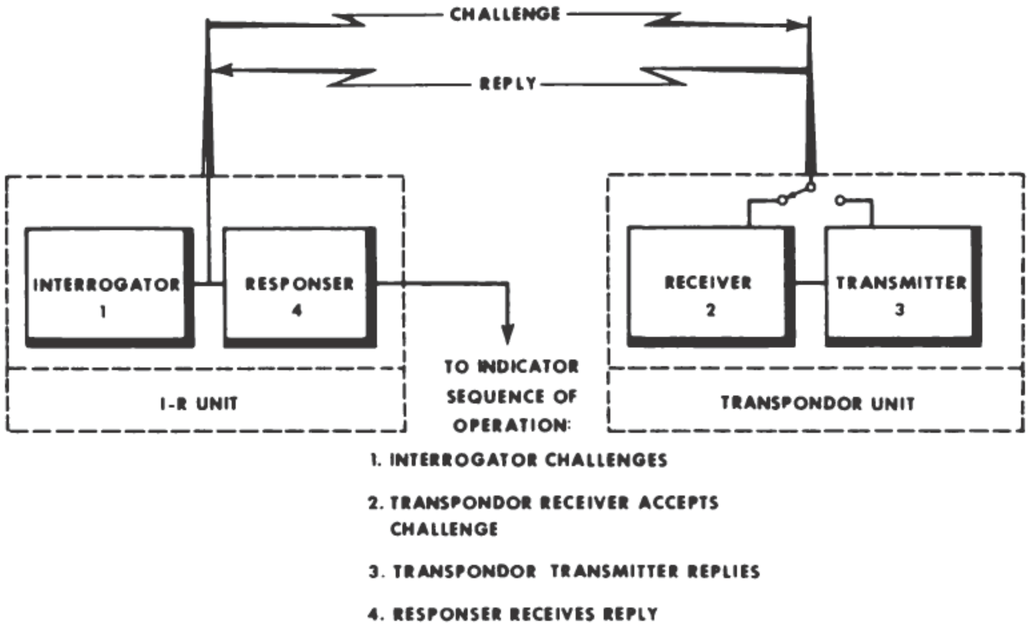


Figure 2–9.—Basic IFF operation.

of identifying the target is necessary because the radarscope shows all objects in much the same way with the images differing only in amplitude and without identifying detail.

The basic operation of an IFF system and the essential units involved are shown in figure 2–9.

The elements of the system consist of the INTERROGATOR, the TRANSPONDOR, and the RESPONSER. The interrogator is a pulse-type transmitter which acts as the challenger. When a radar operator sights an unidentified target on the radar, he sets the interrogator in operation and it emits coded challenging pulses.

The challenge is received by the transpondor which is a receiver-transmitter, also of the pulse type. Upon receiving the proper challenge, it automatically transmits a coded identifying reply. The transpondor is kept in a standby condition and transmits only when the proper interrogating signal is received. Almost all aircraft and ships of the armed forces carry transpondors since this is the unit which provides identity when challenged.

The responser is a receiver which accepts the reply to the challenge, the coded signal sent out by the transpondor.

The replies are then presented on an indicator which may be either that of the associated radar set or a separate scope. In airborne equipment, the interrogator and responser are usually contained in the same housing and are known as the INTERROGATOR-RESPONDER, or I-R UNIT. Only those aircraft such as patrol planes or all-weather fighters whose mission requires that unknown radar targets be identified immediately carry I-R units.

Since it is very important that the IFF equipment is prevented from falling into enemy hands, the units, in certain cases where this danger exists, may be provided with destructor plugs, each of which contains a small explosive charge. The destructors can be set off by the pilot to cause an explosion which is great enough to destroy the IFF unit without injuring nearby personnel. This is done before making emergency landings in enemy territory.

RADAR BEACONS

Radar beacons, or racons, are pulse repeater stations which are used as navigational aids. The beacon receives pulses from airborne radar transmitters and sends coded identifying pulses in reply. Transmissions are made from the beacon station with nondirectional antennas which provide equal signal coverage in all directions. The beacon reply is displayed on the radarscope of the aircraft to reveal the range, azimuth, and identity of the beacon.

Beacon stations are usually located on land with their positions clearly indicated on charts although sometimes they are carried on ships and aircraft. The equipment consists of a pulse-type receiver-transmitter called a TRANSPONDOR. The receiver does not respond to ordinary search radar transmissions but only to pulses of a certain length (between 2 and 3 microseconds for the microwave frequencies). This prevents unnecessary transmission since the station operates only when interrogated by a search radar working on beacon operation. The beacon reply is sent on a frequency different from that of the interrogating radar pulse. To receive it, the receiver of the aircraft

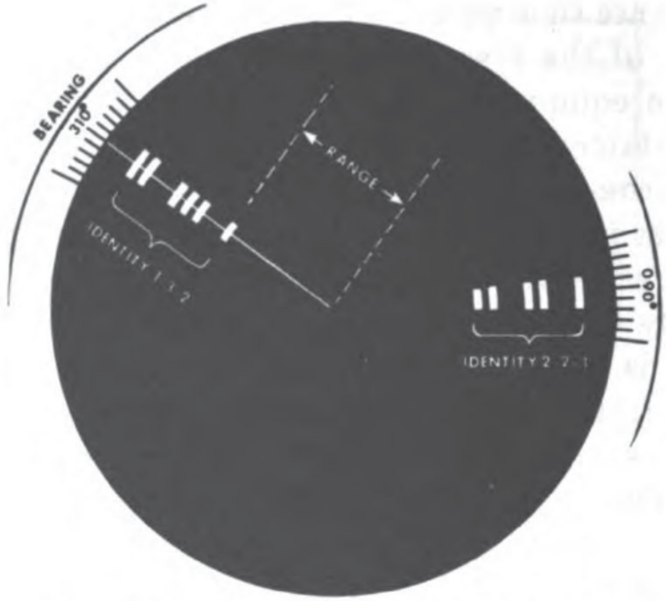


Figure 2–10.—Beacon signals on PPI display.

radar must be retuned from the normal search frequency to that of the racon signals. (This tuning is accomplished quickly and easily from the radar control panel when the set is switched to beacon operation.) Since the radar receiver is then set to a frequency different from that of the outgoing radar pulse, no echoes from targets are displayed on the radar screen and only the beacon pulses are visible.

Beacon operation permits observation of targets whose positions are fixed and known. When more than one beacon station is in the area scanned, several beacon signals can be displayed simultaneously on the scope. A typical PPI display of two beacons is illustrated in figure 2–10.

The beacon signals reveal the range, bearing, and identity of the beacon station. In the figure, the range is determined by measuring the indicated distance to the pulse nearest the center of the screen. Negligible delay is involved in the beacon response, and the inside pulse represents the first signal returned in answer to the radar interrogation.

The azimuth, or bearing, of the station is determined by the position of a line bisecting the beacon signal on the scope, as shown in figure 2–10, for the signal at 310 degrees of relative bearing. The width of the signal on the screen

depends primarily on the antenna beam width of the scanning radar and does not depend on the azimuth of the station.

To establish identity, the beacon signals are range-coded. That is, a series of two to six pulses is transmitted in a group with short time intervals between. On the radar screen the pulses appear separated by range spaces. The station is identified by counting the number of pulses in the group, reading from near to far range. In figure 2–10, the code of the beacon signal at 310 degrees is 1–3–2 while the group at 90 degrees is 2–2–1. The assigned codes and the positions of land-based racons can be found from aircraft navigational charts.

Beacon transpondors are installed on many aircraft carriers for homing purposes and are carried in some aircraft. The code assignment of the mobile stations are changed at intervals and must be determined prior to flight by reference to the proper classified publications.

RADAR ALTIMETERS

Radar altimeters are used to measure absolute altitude, the distance separating the aircraft and the terrain beneath it. The principal function of this radar device is range measurement in which the target is the land or sea surface below the plane. And as in other examples of radar ranging, distance is determined by making indirect measurements of time. The time interval of significance is that required for the transmitted signal to reach the ground or sea below the plane and to return.

Since its operation does not depend on atmospheric data, the radar altimeter is free from some of the disadvantages of barometric altimeters. It requires no recalibration when flying from one pressure area to another; and it removes the necessity for learning the terrain altitude from navigational maps in order to determine the terrain clearance of the aircraft.

Two basic types of radar altimeters are in use. One of these is a continuous-wave, frequency-modulated system.

The other is a pulse device in which the operation is similar in principle to most search radar sets. The c-w, f-m altimeter system is best illustrated by the AN/APN–22 equipment, which is described briefly in this section. The SCR–718 altimeter is an example of pulsed equipment.

The AN/APN–22 radar altimeter radiates a microwave signal which varies regularly in frequency in accordance with a 120-cycle triangular modulating voltage. The signal is directed toward the ground where a portion of it is reflected back to the receiving antenna. The echo wave is compared in the receiver with the instantaneous output frequency of the transmitter. An interval of time elapses between the moment the signal is transmitted and its arrival by reflection at the receiver. This time interval is directly proportional to the altitude of the aircraft since the wave travels with constant velocity. During this same interval of time the frequency of the transmitter changes. The echo wave and a portion of the transmitter output are applied to a balanced detector so that a heterodyne, or difference, frequency is produced. The value of the difference frequency in cycles is proportional to the time interval during which the wave travels to the ground and returns, and hence it is proportional to the altitude of the aircraft.

The value in cycles of the heterodyne difference frequency depends on three factors, the relation being as follows:

$$f_d = \frac{f_m B h}{246}$$

in which f_d is the difference frequency in cycles, f_m is the sweep frequency of the modulator, B is the sweep width (the peak-to-peak frequency change of the transmitter in one cycle of modulation), and h is the altitude in feet or one-half the distance the radio wave travels. The difference frequency can be used as a measure of altitude as long as the sweep frequency (f_m) and sweep width (B) are held constant.

In the AN/APN–22 system, the transmitter output is frequency-modulated by triangular waves at a frequency of

120 cycles per second. The sweep width is held constant at altitudes from 0 to 200 feet, and the difference frequency is used as a measure of altitude. Above 200 feet, the sweep width (B in the equation) is varied so that the difference frequency remains constant and the value of the sweep width is used as the measure of altitude. A servo system is employed to measure the difference frequency and to control the sweep width. It also positions the pointer of the indicator for the proper altitude.

The AN/APN–22 operates in the band from 4,200 to 4,400 megacycles. It provides reliable altitude information up to 10,000 feet when flying over land and up to 20,000 feet over water. The principal units of the installation are the RECEIVER-TRANSMITTER, the ELECTRONIC CONTROL AMPLIFIER, and the HEIGHT INDICATOR.

The RECEIVER-TRANSMITTER is mounted on the underside of either a wing or the horizontal stabilizer or beneath the fuselage of the aircraft. The unit contains two horn antennas, the transmitter magnetron oscillator, a modulation transformer, and the two crystals used in the balanced detector. The RECEIVER-TRANSMITTER radiates the microwave carrier, receives the reflected signal, and produces the heterodyne difference frequency. The transmitter section contains the magnetron which produces the microwave energy and a waveguide r-f system used to feed the transmitting antenna. The magnetron is frequency modulated by a vibrating reed which varies the capacitance across the straps of the anode cavity. The reed is a small metal cup mounted within the magnetic field. It contains two coils similar to those in loudspeakers—one coil is used to drive the modulating reed and the other provides feedback voltage for controlling the reed motion.

The transmitter frequency deviation is about 60 megacycles at altitudes from 0 to 200 feet. From 200 to 20,000 feet, the frequency deviation depends on altitude and is reduced from 60 to about 0.6 mc. over this altitude range.

The average output power of the magnetron is about 1 watt. The energy is coupled to the transmitter waveguide

by a short length of coaxial cable and is radiated from the transmitting horn antenna which is attached to the waveguide. A small portion of the magnetron output is also coupled to the balanced detector where it is mixed with the echo signals.

The balanced detector is a short length of waveguide containing two carefully matched crystal diodes. The diodes are attached to a special resonant circuit and to a horn radiator which is identical with the transmitting horn and which functions as the receiving antenna. The balanced detector mixes the two microwave signals and produces the difference frequency which is in the audio range. The output is applied to audio amplifier circuits in the ELECTRONIC CONTROL unit.

All the required electronic equipment which is not located in the RECEIVER-TRANSMITTER is contained in the ELECTRONIC CONTROL AMPLIFIER assembly. This unit provides the plate and filament power for the various electron tubes of the system and in addition, serves the following purposes:

1. Generates the f-m sweep voltage for modulating the magnetron.
2. Amplifies the heterodyne difference signal and converts it to a d-c voltage that is proportional to the detected frequency.
3. Employs the d-c voltage to drive a servo system which measures the beat frequency at altitudes up to 200 feet. Above 200 feet, the control unit varies the amplitude of the f-m sweep voltage to determine the altitude.
4. Provides a synchro output voltage used to drive the indicator so as to give the altitude value.
5. Determines the reliability of the received signal and produces a warning indication if the received signal is of insufficient amplitude for correct operation.

The HEIGHT INDICATOR of the AN/APN–22 displays the altitude information by means of a synchro-driven pointer and a scale calibrated in feet. The pointer repeats the position of the servo in the ELECTRONIC CONTROL unit, giving a reading in feet of altitude as long as the signal received by

reflection is adequate for reliable operation. In unreliable operation, the synchro which positions the pointer is disconnected from the control unit and a positioning voltage is applied, causing the pointer to assume an off-scale position.

The indicator unit also contains a LIMIT ALTITUDE system in which a red light is caused to glow when the altimeter reveals that the plane is flying at a selected altitude or below this altitude. A potentiometer is included which transmits the limit altitude setting to the automatic pilot.

The only operating control of the AN/APN–22 equipment is the ON-LIMIT knob with which the limit altitude is set and with which the equipment is turned off or on.

The two basic types of radar altimeters differ somewhat in accuracy. The SCR–718 pulse altimeter has a fixed error of approximately 50 feet which is independent of altitude. The error inherent in the f-m, c-w altimeter is based on a percentage of the altitude indication (plus-or-minus 2 feet from 0 to 40 feet; and plus-or-minus 5 percent of the correct terrain clearance from 40 to 20,000 feet for the AN/APN–22 radar altimeter). Because of these accuracy characteristics of the two types of altimeters, the f-m, c-w altimeter is superior for low altitudes while the pulse altimeter is required for high altitude use.

AIRCRAFT EARLY WARNING

The AEW system serves to extend the radar horizon of search radar equipment by means of a relay link. A high-powered airborne search radar collects radar data and relays it to monitoring units. The monitoring units may be shipboard, land-based, or airborne installations. The relay link extends the area of radar coverage in any one direction by the distance over which the relay link is effective. In addition, the area covered by shipboard or land-based radar is enlarged since the airborne unit operates at a high altitude with a greatly extended horizon. The airborne radar used for collecting the radar information is characterized by very high power and a large antenna in order to obtain maximum range. The maneuverability of the plane in contrast to the slow-moving ship increases the amount of data which

can be assembled and used at the station receiving the relayed data.

RADAR BOMBING ATTACHMENTS

These are separate pieces of equipment that are connected to the search radar equipment. Their main use is for making blind bombing attacks through clouds and overcast when visibility is limited. The accuracy gained with some of these attachments approaches that of an optical bombsight on a clear day.

The heart of the bombing attachment is the computer unit which calculates electronically the point of release for a target shown on the search radar screen. The bombs are automatically released at the right instant. The attachments may include a separate bombardier's B-scan indicator which presents the same target information shown on the search radar. With such equipment the skilled bombardier can eliminate drift and bring the aircraft on the proper course to the point of bomb release.

RADAR ANTENNAS

The radar antenna in almost every case must transmit and receive radio energy in very narrow and concentrated beams. Highly directional radiation patterns are needed to insure strong echoes and also to reveal the exact bearings of the targets. The antennas employed usually consist of movable reflectors equipped with devices for feeding energy into them.

The use of antenna assemblies such as these is one of the advantages of operation in the microwave region of the radio spectrum. Microwaves have characteristics which are similar in many respects to those of visible light. If a light source is placed at the focal point of a parabolic (dish-shaped) mirror, a concentrated beam is produced, and the width of the beam depends on the diameter of the mirror. Similarly, if a metal reflector of the same general shape is used instead of the mirror, and if a source of microwave radiation is placed at the focal point, the metal reflector emits a beam of electromagnetic waves. The width of the

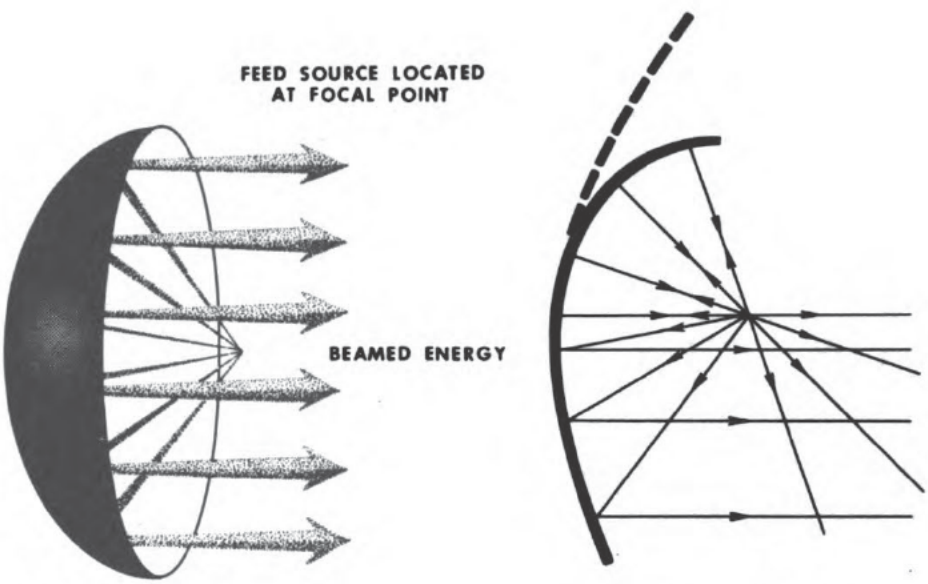


Figure 2-11.—Action of reflector on microwaves. (A) Paraboloid reflector; (B) shaped reflector.

microwave beam also depends on the diameter of the reflector—for a given wavelength, the wider the reflector, the narrower is the projected beam.

The concentration of microwave energy is illustrated in (A) of figure 2–11. As shown in (B) of the figure, the beam can be distorted and directed in desired paths by the use of special reflector shapes.

Two types of reflectors, the paraboloidal and the cosecant-squared, are widely used in aircraft radar.

PARABOLOIDAL REFLECTORS.—These surfaces are uniformly curved and produce a narrow beam which is circular in cross section. The radiated energy is highly concentrated, and beams of this pattern produce strong echoes at long ranges. One of the principal applications of paraboloidal dishes is in fire control radar. They are also used in intercept and acquisition operations in all-weather fighters.

COSECANT-SQUARED REFLECTORS.—The beam emitted by the paraboloidal dish covers only a small part of the target area at any one time; and for this reason, a modified form of the paraboloid, called a cosecant-squared reflector, is usually employed for search and navigation operations. This reflector is similar to the paraboloid except that the

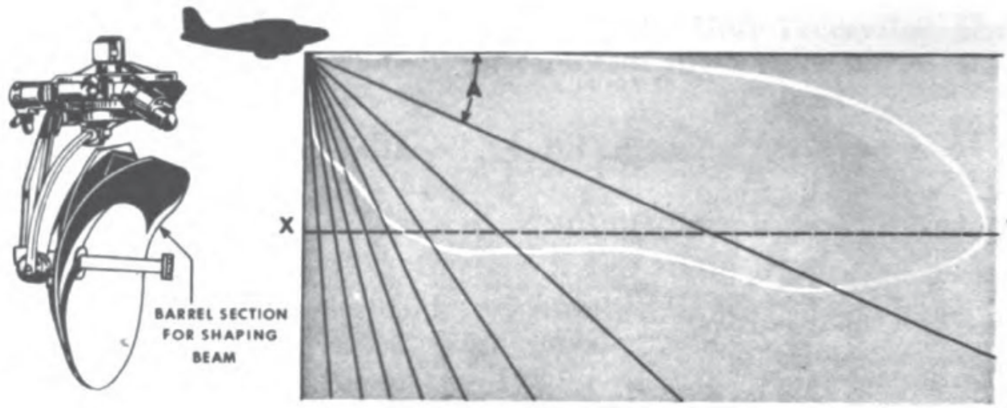


Figure 2–12.—Cosecant-squared reflector and vertical radiation pattern.

upper edge of the dish is bent forward to form a sort of visor. The visor directs much of the outgoing energy in a downward direction so that a fan-shaped pattern results.

The radiation from the cosecant-squared reflector is narrow in the horizontal plane and is distributed vertically as shown in figure 2–12. With this type of coverage the radar receives echoes of approximately equal strength along the line xy in the figure. The name of the reflector is derived from a property of the vertical radiation pattern: The power density of the radiation varies with direction, being proportional to the square of the cosecant of the angle measured from the horizontal. (Angle A of fig. 2–12.)

Two methods of feeding microwave energy into antenna reflectors are shown in figure 2–13. In (B) two dipoles are

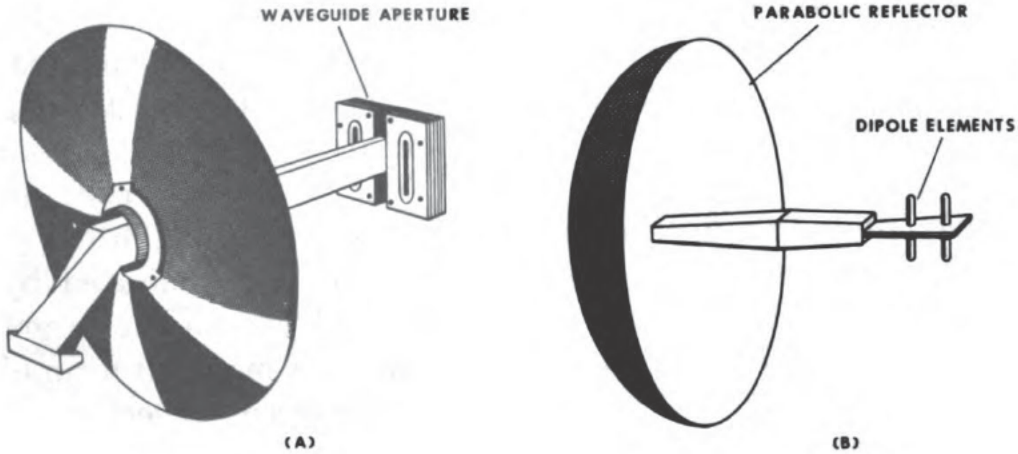


Figure 2–13.—Methods of feed.

located at the focal point of the dish and receive energy from a waveguide. The length and position of the dipoles is such that they radiate to the left, sending energy in a cone-shaped pattern which misses the opening of the waveguide and strikes the reflector dish. In the arrangement shown in (A), the microwave radiation flows from apertures in the waveguide termination which is located at the reflector focal point. The radiation is directed backward into the paraboloid.

HORN RADIATORS.—Horn radiators are often used to obtain directive radiation of microwave energy and are frequently employed as primary feed sources in radar antenna assemblies. The operation of an electromagnetic horn is

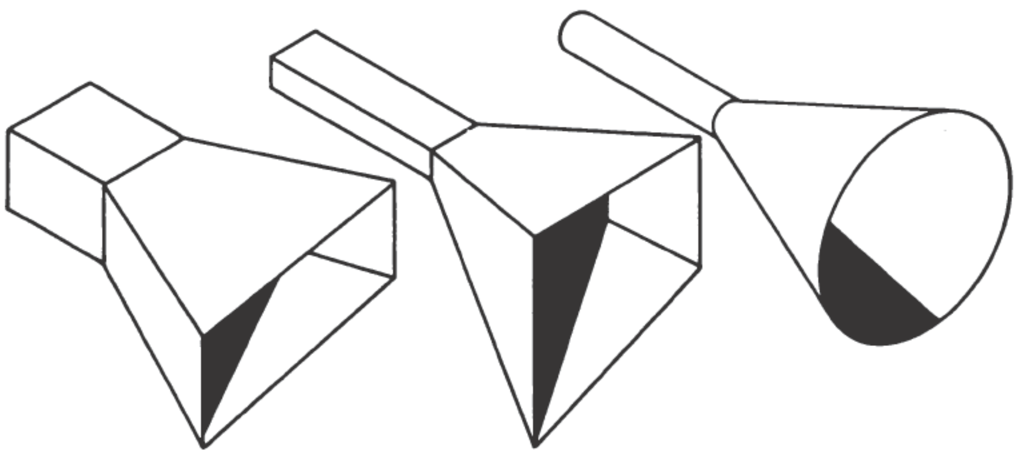


Figure 2–14.—Types of horn radiators.

similar to that of acoustic horns. However, the throat of an acoustic horn usually has dimensions much smaller than the sound wavelengths for which it is used, while the electromagnetic horn has dimensions which are comparable to the wavelength being radiated. Horn radiators are essentially sections of waveguide with open, flared ends. They act as terminations for transmission lines, especially waveguides. The horn can be considered as a type of transformer which matches the wave impedance of the waveguide to the wave impedance of free space. With the transmission line so terminated, there is little reflection of waves at the end and the energy flows into the surrounding space.

Horns may be constructed in a variety of shapes. Some of the basic types are shown in figure 2–14. They are useful in microwave applications since they not only match the impedance of the waveguide to external space but also produce directive wave patterns. The shape of the horn along the dimensions of the mouth measured in terms of wavelength determines the radiation pattern. In general, the larger the opening of the horn, the more directive is the resulting pattern for a given wavelength. An aperture of about five wavelengths gives a radiated major lobe of approximately 30 degrees.

RADOMES.—In all installations of radar in aircraft, a protective cover or shell is used to enclose the antenna assembly and to reduce aerodynamic drag. The cover is called a radome. Electrically, the material from which the radome is made must be as nearly invisible to radar waves as possible, since both outgoing and reflected pulses pass through it. The material must be light in weight. Mechanically the cover must have high strength to resist stresses caused by high speed, skids, slips, and yaw. It must be strong enough to resist shock waves and concussion caused by gunfire and must be nonshattering when struck by enemy fire.

Radome structures are designed to keep their shapes under the effects of exhaust gas, sun, rain, ice, and rapid changes in temperature, pressure, and humidity. The material must shed water and retain very little surface moisture which would absorb and reflect radar beams. In addition to all these properties, in some installations the radome is required to be airtight to allow pressurization of the enclosed antenna assembly.

LORAN

Loran is a long-range navigational system developed primarily to provide a means for making geographical fixes by the use of low-frequency radio signals. With loran equipment, the navigator determines his position by measuring the difference in the time required for radio pulses to arrive from two or more pairs of land-based transmitters.

The system is a valuable aid to air navigation since loran fixes can be made quickly and accurately both by night and by day. Under ordinary conditions, an initial fix can be made in about three minutes. Thereafter a fix can be established in one minute or less. Operation is unhindered by fog and foul weather, and the signals are available over long distances. Newer receivers such as the AN/APN-70 provide dual delay channels giving a direct time difference reading for each LOP required for a fix, on a Veeder-Root counter.

Standard loran transmissions are made on four frequency channels situated between 1.7 and 2 megacycles. Operation at these frequencies gives long-range coverage, employing both ground waves and sky waves. The useful range for day operation over sea water is about 700 miles. At night the distance is greater, extending up to 1,400 miles. In addition to standard loran, low-frequency, (l-f), loran facilities are available which operate on two channels from 90 to 110 kc. and from 170 to 190 kc.

In principle, loran differs from radar in that the airborne (or shipboard) unit simply receives radio pulses broadcast from ground stations, and no reception of echo signals is involved. The basic loran measurement is that of time difference of signals with no regard to the direction from which they arrive; hence, the complicated directional antennas such as used in radar equipment are unnecessary. Despite these differences, however, loran is closely related to radar since it is a pulse type of equipment, and it employs radar techniques of time measurement. Also, visual displays of the signals received are made on cathode-ray tubes used as indicators.

The basic principle of the system is illustrated in figure 2–15. The use of the system involves the following procedures:

1. Radio signals consisting of short pulses are broadcast from a pair of ground-based transmitting stations.
2. The signals are received on special loran receivers located in the aircraft or ship.
3. The difference in the time of arrival of corresponding

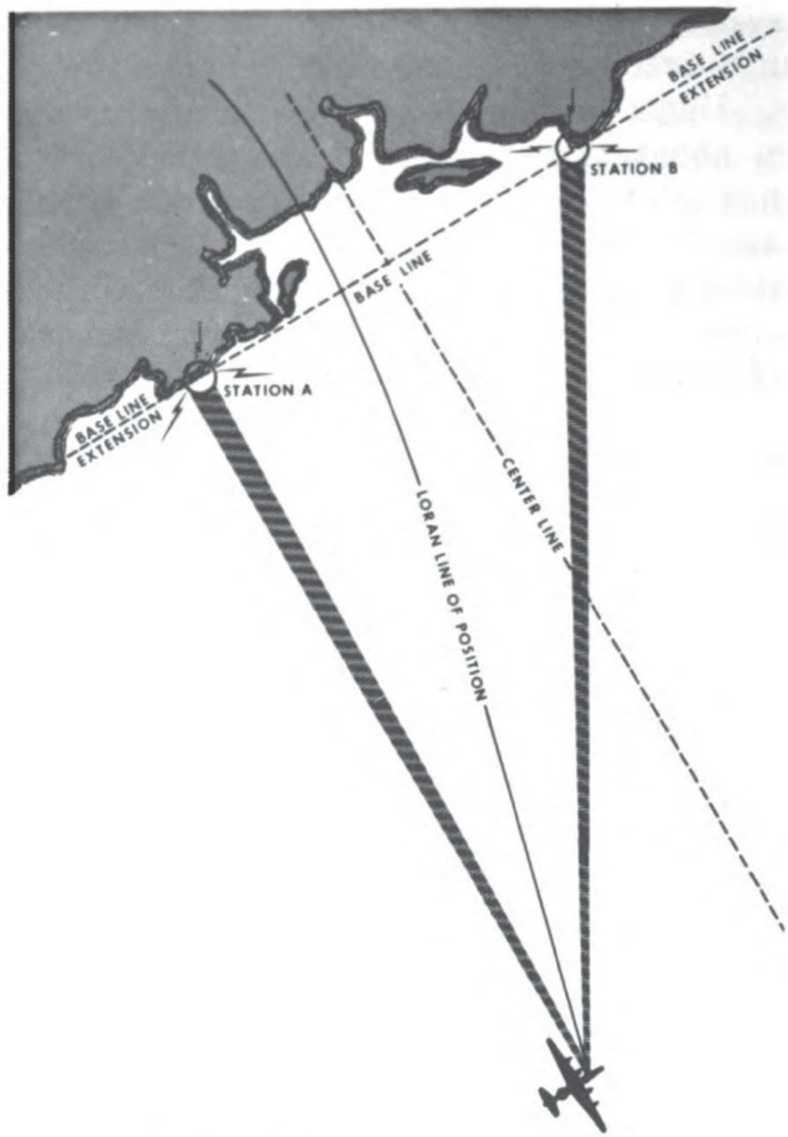


Figure 2–15.—The principle of loran.

pulses from the two stations is measured on the loran indicator.

4. The value of the time difference is used to identify a line of position on a loran chart.
5. Two or more lines of position are found by time difference measurements from two or more pairs of stations. The intersection of the lines of position gives the location of the observer.

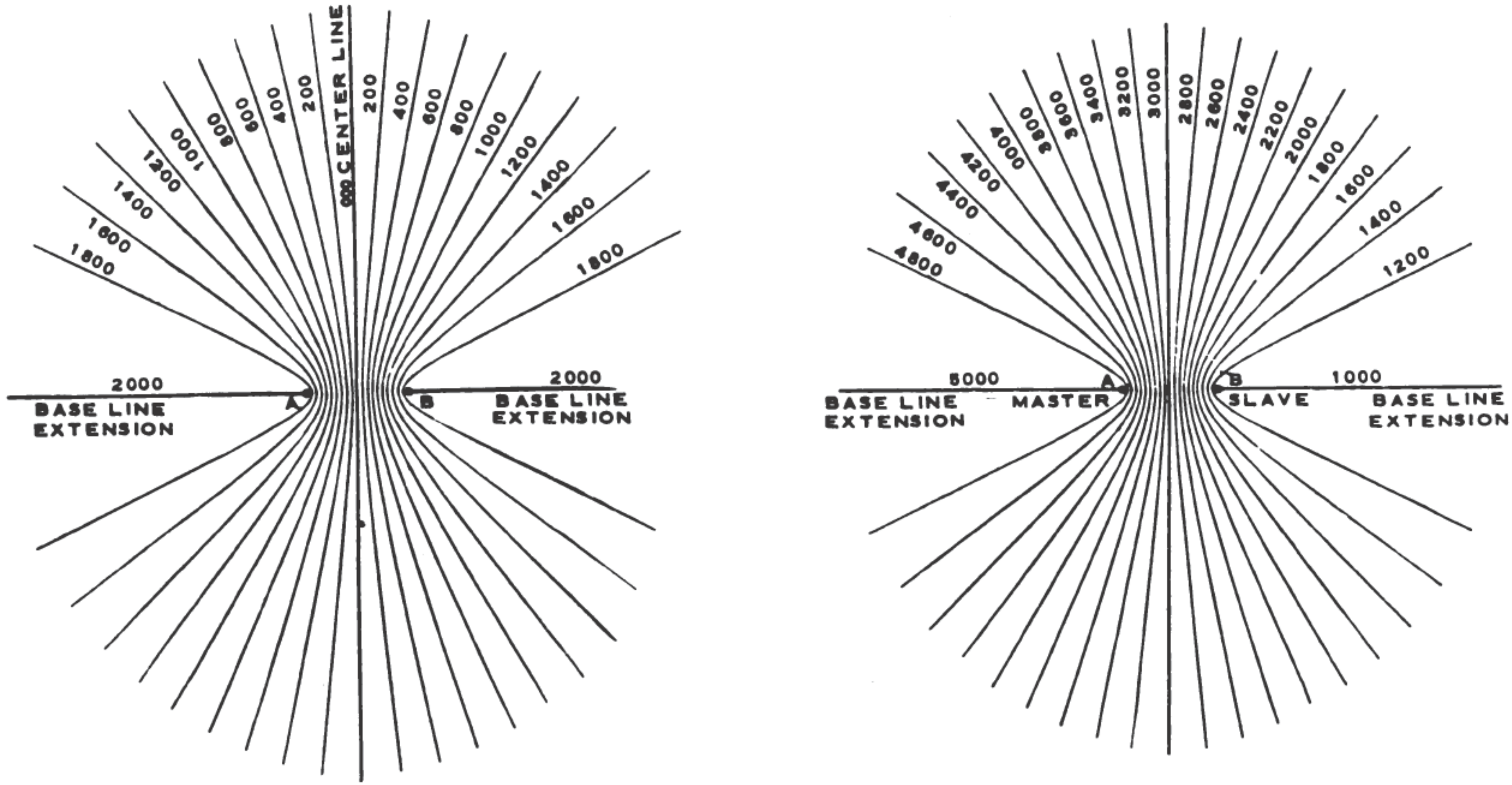
As shown in figure 2–15, two stations are necessary to establish a loran line of position. One transmitter, called the

MASTER STATION, emits a series of uniformly spaced pulses each second. The number of pulses radiated per second is called the pulse recurrence rate (PRR). At a considerable distance from the master station (usually several hundred miles), a second transmitter, called the SLAVE STATION, sends out a similar series of pulses which are synchronized with the master pulses. The difference in arrival time of the master and slave pulses at the observing station determines the particular line of position on which the observer is located.

In figure 2–15, the line joining the two stations is called the base line, and its perpendicular is called the center line. The base line extension is a straight line drawn beyond either station as a continuation of the base line. Assume that the two stations are sending out pulses simultaneously. Then at any point along the center line, the two signals arrive at the same instant since all points of the line are equidistant from the two transmitters. If the observer is located nearer station *A* than station *B*, the *A* pulse arrives first followed after a measurable time interval by the corresponding *B* pulse. If the observer moves in a path so that the pulses always arrive with the same time interval, he then traces out a loran line of position.

A number of lines of position can be drawn for each pair of loran transmitters as shown in figure 2–16. Each line is labeled with a number indicating the time interval in microseconds between the arrival of the corresponding loran pulses. In (A) zero time difference exists along the center line and maximum time difference along the base line extensions. The curves are hyperbolas since this curve is the path traced by a point which moves so that the difference of its distances from two fixed points remains constant. (For this reason loran is called a hyperbolic system of navigation.)

In (A) of figure 2–16, lines with the same time difference are found on each side of the center line since there is no way of telling which signal is from which station. Hence, if the simultaneous method of signal transmission were used, it would be necessary to identify the signals from each station of a pair. In actual practice the signals are not sent simul-



A

B

Figure 2-16.—Lines of position. (A) No time delay; (B) 3,000-microsecond delay.

taneously, but the slave station pulse is delayed so that at any point the master station pulse is received before the corresponding slave signal. As a result, each line of the family of curves has a different time interval value as shown in (B) of the figure.

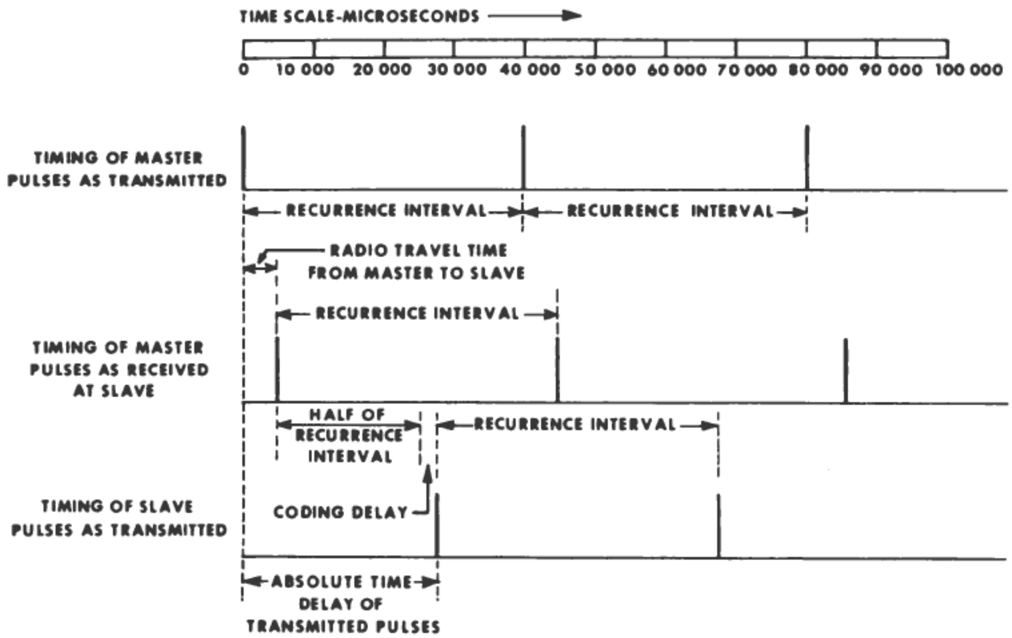


Figure 2–17.—Time relationship of actual loran pair.

The method of staggered, or delayed, pulsing is shown in figure 2–17. The master (or A) station transmits a pulse. An interval of time elapses during which the signal reaches the slave station. The slave station receives the impulses and waits a period of time equal to one-half the pulse recurrence interval plus another period of time called the coding delay. It then emits a pulse. The sum of the travel time, half the recurrence interval, and the coding delay is called the absolute delay. As a result of the delay, the master pulse always precedes the slave signal at any point of reception. The difference in arrival time is maximum along the base line extension beyond the master station and minimum on the base line extension beyond the slave transmitter, as shown in (B) of figure 2–16.

For use aboard aircraft and ships the Hydrographic Office

publishes loran charts which are standard Mercator charts with loran lines of position superimposed. The lines are computed mathematically, taking into account the coding delay, the curvature of the earth, and other factors. (If required by reasons of security, it would be possible to change the coding delay. A coding correction would then be issued to navigators using the charts. The system would be useful only to persons knowing the proper correction.) The use of the chart in obtaining a loran fix is illustrated in figure 2–18.

A loran chart shows the lines of position of one station pair crossing those of another. In many installations, the two pairs consist of a single master station operating in conjunction with two slave transmitters. This is called double-pulsed transmission and is the type represented in figure 2–18. The common master station emits two sets of pulses. Each set is synchronized with one of the adjacent slave stations. In the figure, the master station is labeled P and the slave stations, R and Q. The combination P–R operates with a different pulse recurrence rate than does the combination P–Q. Two families of lines are available, and the fix is made by taking measurements on both pairs, locating the observer at point x.

The lines of position are identified on the chart by a letter and several numbers. The letter represents the basic pulse recurrence rate: special (S), low (L), and high (H). (The special rate is not in current operational use.) The first number is the channel or carrier frequency symbol. The second number denotes the specific pulse recurrence rate. The last number is the time difference (in microseconds) for the line of position. As an example, 2L 6–2500 indicates channel 2 (1,850 kilocycles), a low basic pulse recurrence rate (25 cycles per second), a specific pulse recurrence rate of 6 (corresponding to 25⁶⁄₁₆ c. p. s.), and a time difference of 2,500 microseconds.

When loran fixes are made, the general position of the craft is usually known. The navigator consults the loran chart for that particular area and selects a station pair by setting the receiver controls according to the symbols given on the chart. The principal receiver settings are for channel

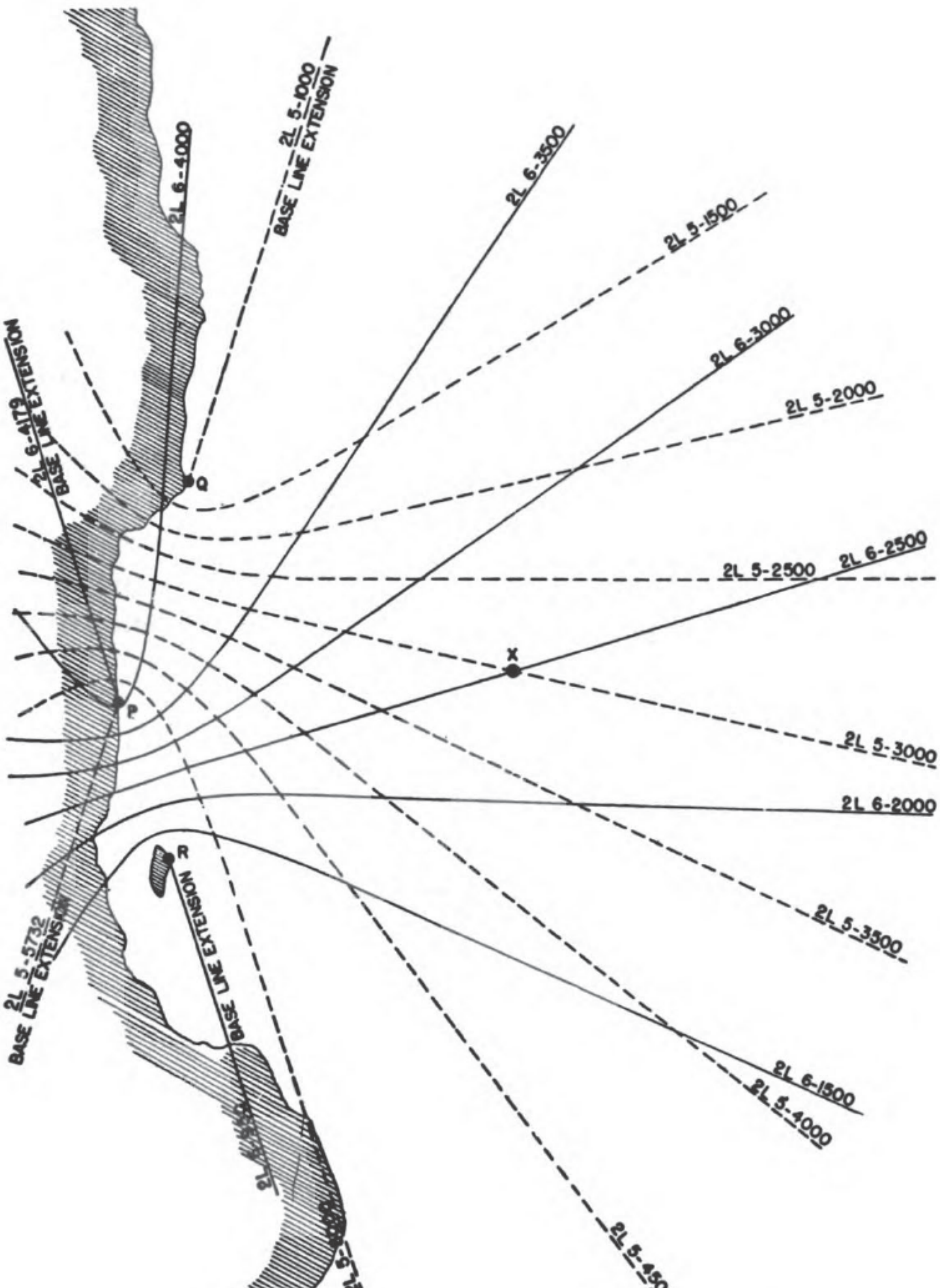


Figure 2–18.—Method of obtaining a loran fix.

frequency, basic pulse recurrence rate, and specific pulse recurrence rate.

Loran stations operate in a portion of the radio spectrum which is very crowded; and to conserve space, several station pairs are operated on the same r-f carrier frequency. Each pair emits pulses at a different rate; and by this means, the receiver distinguishes between stations on the same channel. The receiver displays the loran pulses visually on a cathode-ray tube indicator. After channel selection, pulses from many stations are present on the indicator. One set of these is selected by synchronizing the sweep in the indicator tube with the rate at which the desired pulses occur. When the number of patterns the indicator traces each second is equal to the pulse recurrence rate of the desired station pair, the signals remain stationary on the screen. Pulses from other stations drift across the screen and can be ignored. The general appearance of the indicator display is shown in figure 2–19.

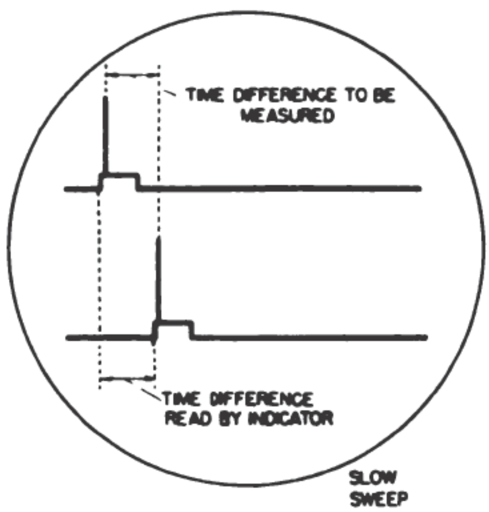


Figure 2–19.—Time difference measured on a loran indicator.

The electron beam in the indicator tube traces two time base lines, one above the other. Moving from left to right, it slowly traces the upper line in a period of time equal to one-half the pulse recurrence interval. It quickly retraces, jumping to the left and below. It then traces the

lower base line in one-half the recurrence interval before rapidly retracing to the start of another top line.

The master station pulse is superimposed on the upper base line and the slave pulse appears on the lower when the receiver is correctly adjusted. The station pulses are displayed above pedestals, rectangular deflections in the time base lines which indicate portions of the display which can be expanded and examined in greater detail for accurate measurement. The time difference to be measured is represented by the horizontal distance between the master pulse on the left and the slave pulse below it to the right. This method of measuring the time difference automatically cancels the fixed delay of one-half the recurrence rate by which the slave pulse was retarded during transmission. The time difference reading is indicated by a Veeder-Root counter on present-day direct-reading loran.

QUIZ

1. The type of modulation most frequently employed in airborne radar transmitters is
   a. CW
   b. MCW
   c. FM
   d. Pulse
2. In the operation of Navy search radar, range is usually measured in
   a. statute miles
   b. nautical miles
   c. yards
   d. meters
3. The total travel time of a pulse of r-f energy is known to be 618 microseconds. What is the range of the target that reflected the energy?
   a. 50 miles
   b. 100 miles
   c. 25 miles
   d. 10 miles

4. An electron beam sweeps across a five-inch cathode-ray tube in 123.6 microseconds. This trace represents
   a. 5 miles of radar range
   b. 20 miles of radar range
   c. 2.5 miles of radar range
   d. 10 miles of radar range

5. The trace on a cathode-ray tube is modulated by range markers every 247.2 microseconds. The resulting markers divide the screen into
   a. 40 mile segments
   b. 20 mile segments
   c. 10 mile segments
   d. 5 mile segments

6. Plan position indicators (PPI)
   a. are not normally used in airborne radar
   b. indicate range and target elevation
   c. indicate target range and bearing
   d. are best suited for intercept radar

7. The radar synchronizer circuits produce
   a. trigger pulses which coordinate other circuits
   b. high-voltage square waves which trigger the transmitter
   c. extremely high-frequency oscillations
   d. a visual display of received targets

8. The radar modulator circuits produce
   a. a visual display of received targets
   b. extremely high-frequency oscillations
   c. high-voltage square waves which trigger the transmitter
   d. trigger pulses which coordinate other circuits

9. In radar displays, the time trace is produced by applying sawtooth variations to which of the following elements of the cathode-ray tube?
   a. Control grid
   b. Cathode
   c. Deflection system
   d. Collector ring

10. A typical all-weather attack radar
    a. cannot be used for locating beacon stations
    b. would have a low PRF (pulse repetition frequency)
    c. will show the altitude of the target with respect to the fighter plane
    d. uses a fixed antenna

11. Which of the following types of presentation is often employed in gun-aim displays?
    a. B scan
    b. PPI (plan position indicator)
    c. Acquisition scan
    d. G scan
12. A radar system using the "Palmer Scan" would be used for
    a. search operation
    b. intercept operation
    c. mapping operation
    d. bombing operation
13. Racons are used primarily as
    a. recognition aids
    b. auxiliary bombing equipment
    c. AEW equipment
    d. navigational aids
14. Radar altimeters
    a. can be used only in aircraft equipped with radar
    b. measure altitude with respect to sea level
    c. measure altitude with respect to terrain
    d. are always c-w equipments
15. Airborne early warning radar is characterized by
    a. low power and a large antenna
    b. high power and a small antenna
    c. high power and a large antenna
    d. low power and a small antenna
16. Increasing the aperture in the end of the flared section of a horn radiator will
    a. increase the area coverage in the horizontal plane
    b. reduce the antenna power gain
    c. increase antenna directivity
    d. decrease antenna directivity
17. Horn radiators, used in conjunction with aircraft antenna systems,
    a. are sections of waveguide with open, flared ends
    b. act as terminating devices for the parabolic reflector
    c. are quarter-wave shorted stubs and act as supports for the parabolic reflector
    d. are very small in all dimensions compared with one wavelength of the signals they radiate
18. The minimum number of stations required to establish a loran line of position is
    a. one
    b. two
    c. three
    d. four

19. The first number of a group of numbers and letters that identify lines of position on a loran chart denotes
    a. carrier frequency
    b. pulse recurrence frequency
    c. pulse width
    d. range
20. To take a loran time difference reading, the master pulse
    a. and slave pulse must be synchronized on the top trace
    b. and slave pulse must be synchronized on the bottom trace
    c. must be synchronized on the bottom trace and the slave pulse on the top trace
    d. must be synchronized on the top trace and the slave pulse on the bottom trace.
21. In the operation of the loran system, slave transmitters are
    a. pulsed at random intervals
    b. keyed by an operator
    c. triggered by aircraft
    d. triggered by the master transmitter
22. The loran charts published by the Hydrographic Office are which of the following types?
    a. Mercator charts
    b. Gnomonic charts
    c. Polyconic charts
    d. Lambert conformal charts
23. The useful range of loran for day operation is approximately
    a. 1,400 miles
    b. 400 miles
    c. 700 miles
    d. 1,700 miles
24. To synchronize loran signals on the indicator the
    a. sweep frequency must equal the PRF of the master transmitter
    b. sweep time must equal the pulse width of the master transmitter
    c. loran equipment must be within range of the master and slave transmitters
    d. sweep frequency must be some value which is not an exact multiple of the master station pulse rate

CHAPTER 3

AIRCRAFT ELECTRONIC TEST EQUIPMENT

The purpose of this chapter is to provide the aviation electronics technician with information concerning some of the more important test instruments of his specialty. The primary objective of the chapter is to make clear the purposes and uses of the equipment discussed. Discussion of the components of the instruments is given when this is necessary for comprehension of the applications to which the test equipment is customarily made.

An additional source of information on basic types of electronic test equipment is provided in chapter 13 of *Basic Electronics*, NavPers 10087. The basic text contains discussions of many test units which are customarily employed in the work of the AT, including such devices as the synchroscope, the electronic switch, electronic voltmeters and multimeters, grid-dip meters, impedance bridges, and tube testers.

THE CATHODE-RAY OSCILLOSCOPE

The cathode-ray oscilloscope is one of the most useful and versatile of test instruments. It is essentially a device for displaying graphs of rapidly changing voltage or current, but it is also capable of giving information concerning frequency values, phase differences, and voltage amplitude. The oscilloscope is used to trace test signals through radio receivers and audio amplifiers, to measure percentages of

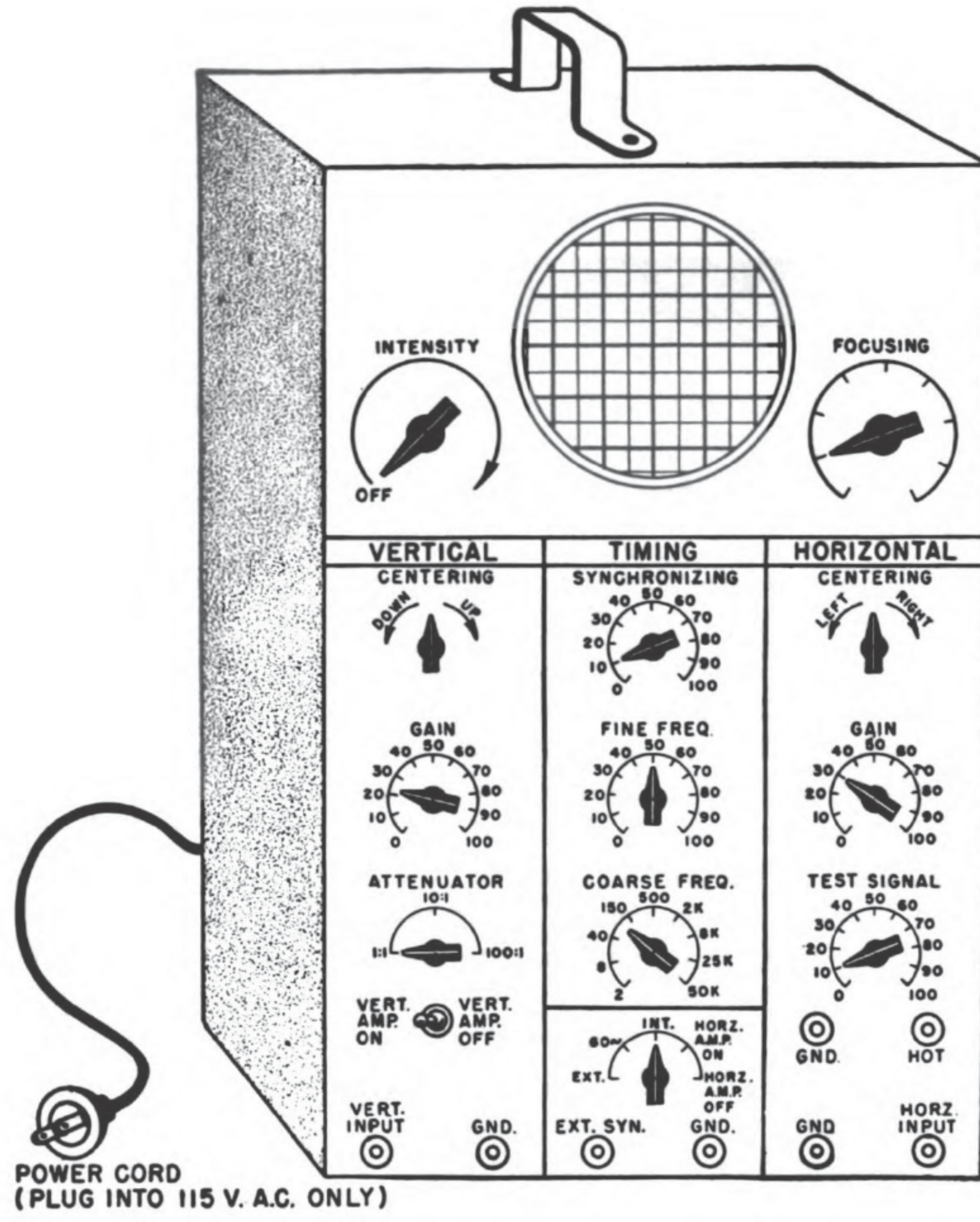


Figure 3–1.—Test oscilloscope.

modulation in transmitters, and to localize the sources of distortion and hum voltages in communication equipment. It is used to measure peak a-c and r-f voltages, to measure audio amplifier gain and fidelity, to make overall frequency response curves, and to study dynamic tube characteristic curves. These are a very few of its many applications.

Discussion is confined here to the basic features of the oscilloscope and to some of its applications to electronic circuit measurement and maintenance.

A typical test oscilloscope which is frequently employed in the maintenance of Navy electronic equipment is illustrated in figure 3–1.

The oscilloscope is based on the cathode-ray tube. In this kind of tube, electrons are emitted from a cathode, accelerated toward a viewing screen, and focused into a narrow ray, or beam. The beam of electrons is deflected in its course both by the voltage (or current) to be studied and by a horizontal sweep voltage, then directed against a screen consisting of a fluorescent material.

Fluorescent materials have the useful property of producing points of visible light when bombarded by beams of fast-moving electrons; and this makes it possible to display the variations of the voltage which deflects the beam. Upon striking the fluorescent screen, the deflected beam produces a visible trace which reveals the nature of the waveform causing the deflection. The fluorescent material with which the screen is coated is called a PHOSPHOR. The phosphor continues to emit light for a short time after the electron bombardment, thus making a continuous line appear on the screen when the beam is swept rapidly over the surface.

The type of cathode-ray tube usually found in test oscilloscopes is illustrated in figure 3–2.

Cathode-Ray Tubes

The cathode-ray tube illustrated in figure 3–2 includes the following major components: The electron gun, a deflection system with two sets of electrostatic deflection plates, and the fluorescent screen.

The electron gun is an assembly for producing and focusing a beam of electrons. The electrons are emitted from a cylindrical cathode, *B*, which is capped with an oxide emitting material. The cathode is indirectly heated by the filament, *A*. Surrounding the cathode is a heat shield, *C*,

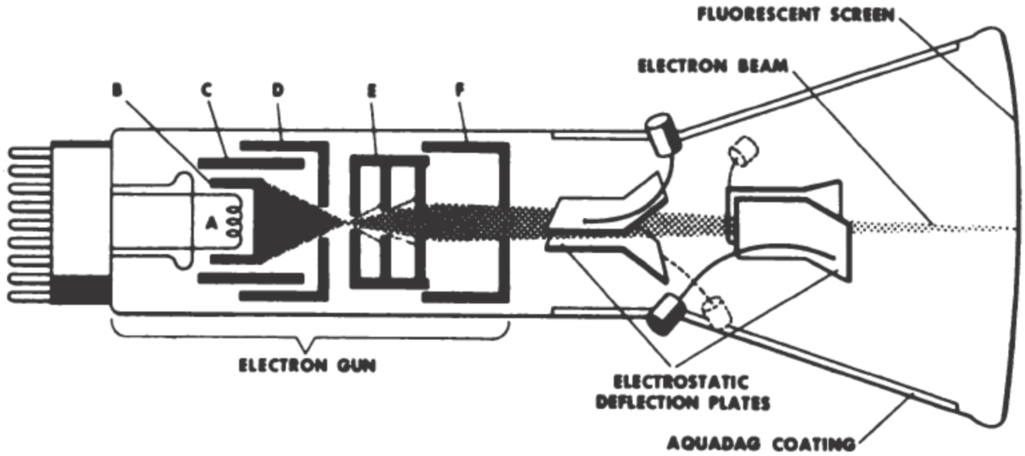


Figure 3–2.—Cathode-ray tube.

which increases the thermal efficiency of the cathode and also assists in preventing electrons from flowing in undesirable directions. (See fig. 3–2.)

A control element, or control grid, *D* (fig. 3–2), is a part of the electron gun. The control grid is a metal cylinder which contains a small aperture, or hole, through which electrons pass as they flow toward the anodes.

The control element performs the same function as a control grid in a triode or pentode tube—it controls the number of electrons in the beam.

Electrons pass through the grid aperture and flow toward two cylindrical anodes. The first, the FOCUSING ANODE, is operated at about 100 to 300 volts positive with respect to the cathode. The second anode, called the ACCELERATING ANODE, is operated at a potential of about 1,000 to 2,000 volts positive with respect to the cathode. The electrons emitted from the cathode are accelerated by the voltages of the anodes, and those which pass through the apertures of the tube electrodes are focused in a narrow beam. The high potential of the second anode imparts enough velocity to the moving electrons so that considerable light is emitted when they strike the fluorescent screen. In addition to providing the accelerating voltage, the second anode in combination with the first anode forms an electron lens. Several electron lenses are present in the gun assembly. These cause the beam to be focused.

In the tube illustrated in figure 3–2, electrostatic deflection is used. The deflection of the beam is caused by the action of voltages which are applied to the two sets of metal deflecting plates mounted perpendicularly in the tube. One set of plates causes horizontal movement of the beam across the screen and the other set of plates causes vertical deflection. Electrons are attracted toward the positive plate and repelled from the negative plate. The amount of beam deflection produced is dependent on the value of the applied voltage and on the speed of the electrons. Slow-moving electrons are in the deflecting field for a comparatively long time and the attractive force of the field has time to produce a large amount of deflection. At higher electron speeds, less deflection occurs with the same deflection potential. If the beam electrons flow at constant speed, the amount of deflection is proportional to the value of the deflecting voltage. Some cathode-ray tubes are designed for electromagnetic deflection which is an alternative system to the electrostatic method. Electromagnetic deflection is caused by the presence of two crossed magnetic fields through which the moving electrons pass. The two magnetic fields are produced by two coils which are mounted perpendicularly outside the neck of the tube. The amount of vertical and horizontal deflection of the beam is dependent on the strength of the currents which flow in the coils.

When the beam strikes the screen it causes secondary emission of electrons from the screen surface. The secondary electrons are collected by a coating of aquadag, a graphite compound, on the inside of the tube. The aquadag coating is usually connected to ground. It attracts the secondary electrons because it is positive with respect to the screen, since the screen assumes a negative potential when bombarded with electrons. The coating serves as a means of completing the circuit from the negative terminal of the power supply, through the electron beam, back to the positive terminal of the power supply by means of secondary emission.

Focusing the Electron Beam

The portion of the cathode-ray tube which provides for focusing the electron beam is illustrated in figure 3–3.

The free electrons emitted from the cathode are attracted toward the positively charged anodes. The barriers in the electrodes intercept some of the particles, but many succeed in passing through the holes and these reach the fluorescent screen. The electrodes shown in the figure form an electron lens system which produces an image of the crossover point on the viewing screen. The crossover point is located between the control grid and the first anode and is the point at which streams of electrons converge as they pass from the grid aperture.

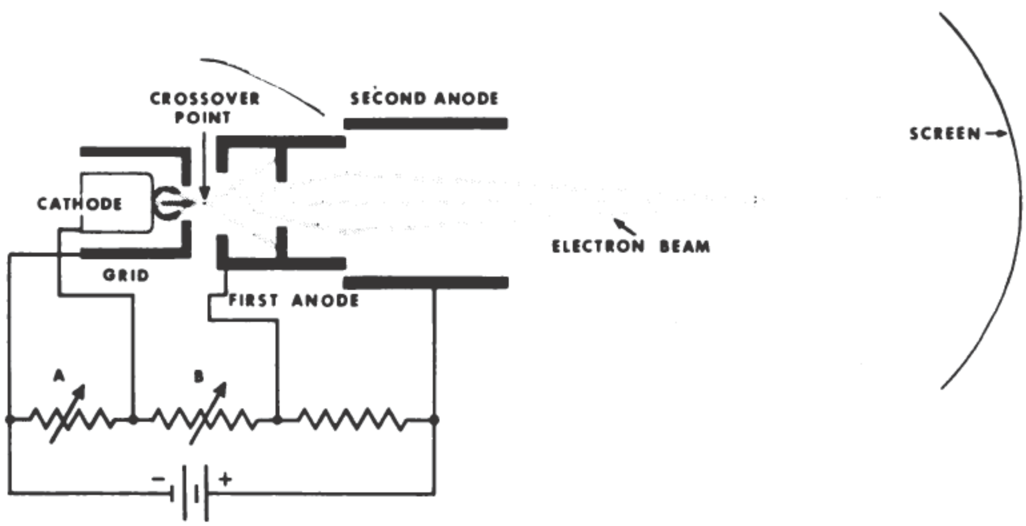


Figure 3–3.—Focusing the electron beam.

The control marked A in figure 3–3 is provided for the purpose of varying the intensity of the beam. By means of this control, the voltage between the cathode and the control element can be adjusted. The adjustment marked B is a focus control that determines the potential of the first anode with respect to the cathode.

The focusing action is dependent on the presence of equipotential surfaces which exist in the spaces between any two electrodes which are different in electrical potential. Equipotential surfaces are layers along which an electron

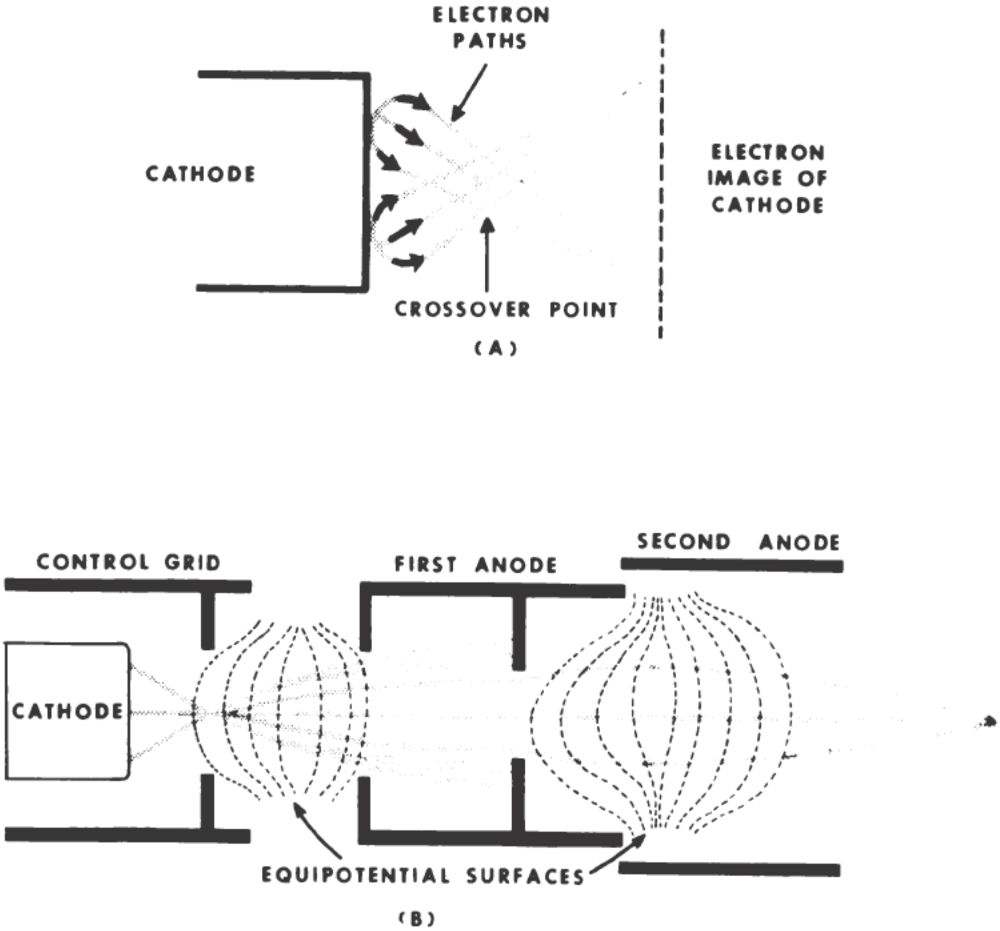


Figure 3–4.—Crossover point and electron lens.

experiences no accelerating force. The direction of the force which moves the electron is perpendicular to the equipotential surfaces, and the action of the force causes the motion of the electron from one surface to another. The shapes of the equipotential surfaces determine the path of electron flow between the electrodes; hence, the curved contours produce a converging effect on the moving electrons. The surfaces constitute an electron lens and have somewhat the same effect on electron motion that a glass lens has on light rays. Exact focus of the beam into a sharply defined spot is controlled by adjusting the potential difference between the first and second anodes. The adjustment of the grid voltage also has some effect on the focus since this voltage determines the position of the crossover point of the electrons. (See fig. 3–4).

In some cathode-ray tubes, the electron beam is focused by a magnetic field rather than by electrostatic fields. In electromagnetic focusing, a coil is placed around the neck of the tube and direct current is passed through it. The current produces a magnetic field which is parallel to the line along which the electrons pass in order to reach the screen. Any electrons which deviate from this path are acted upon by magnetic forces which cause them to describe spiral paths along the tube and converge to a point on the screen.

Oscilloscope Control Circuits

While the oscilloscope is most frequently used for viewing the waveforms of alternating voltages and currents, several direct voltages are necessary for proper operation of the cathode-ray tube. A simple schematic diagram illustrating the direct voltages and controls associated with the operation of the C–R tube as applied to test oscilloscopes is shown in figure 3–5.

High d-c voltage is required to accelerate the electrons originating in the electron gun and to give them sufficient velocity to give usable light upon striking the fluorescent screen. A typical value for the accelerating potential in test oscilloscopes is 1,500 volts. In the circuit shown, this voltage is derived from a half-wave rectifier tube, V1. The high-voltage rectifier produces a negative potential (with respect to ground) which is applied to the cathode of the cathode-ray tube. The second anode is grounded, thereby making it positive with respect to the cathode.

Positive d-c voltage is required for the plate and screen circuits of the additional tubes in the oscilloscope. This voltage is supplied by a full-wave rectifier, V2, the circuit of which produces about 250 volts, positive with respect to ground.

A voltage divider containing several potentiometers is attached across the combined outputs of the high-voltage and low-voltage rectifiers. The intensity control is a variable resistor by means of which the control element is given a negative voltage with respect to the cathode. Variation

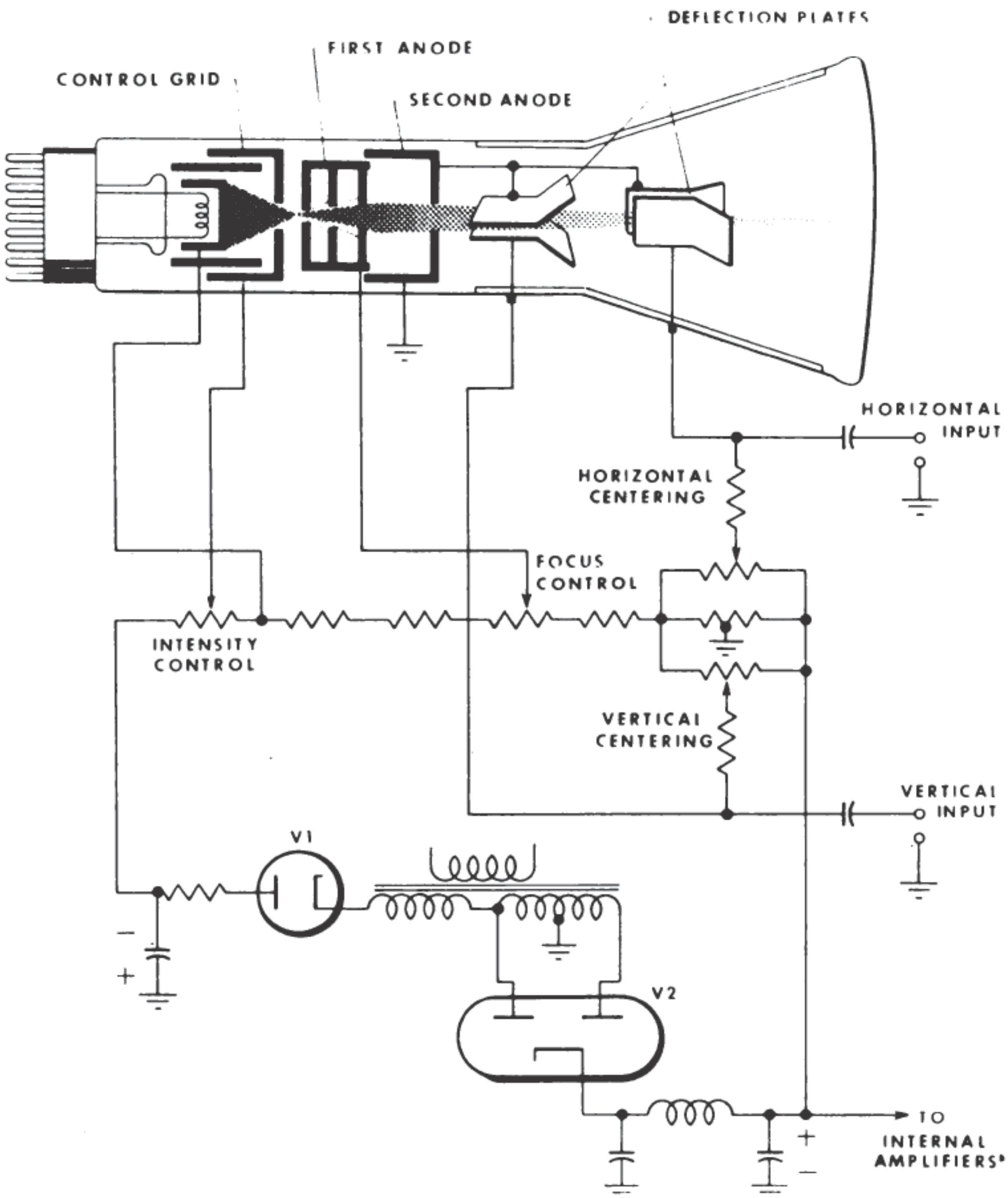


Figure 3–5.—Cathode-ray tube and associated control circuits.

of the control grid voltage causes variation in the intensity of the electron stream.

Focus of the beam into a sharply defined point is achieved by variation of the voltage between the first anode and the cathode. This variation is provided by a potentiometer which is adjusted from the control panel of the instrument.

In the electrostatic deflection system shown in the diagram, one of the horizontal deflecting plates and one of the vertical plates are grounded. In many C–R tubes, none of

the deflecting plates are grounded and push-pull deflection is used.

It is necessary to provide some means of centering the beam on the screen when the instrument is first put in operation and before a signal is applied to the deflecting plates. In the diagram the circuit shown for accomplishing this is typical of the oscilloscopes in which two of the deflecting plates are grounded. A portion of the output of the two rectifiers is applied to a bridge circuit containing two potentiometers. Either potentiometer can be adjusted to give direct positive or negative voltage (or zero voltage) for application to the deflecting plates. The voltages applied are a form of bias by which the operator can center the spot on the screen, both horizontally and vertically, before application of the waveform to be studied.

The deflecting potentials are applied in order to provide movement of the beam on the screen. Since it is desirable to view small signals, it is necessary to amplify such signals before application to the deflecting plates. To provide amplification, the oscilloscope is equipped with internal amplifiers for the horizontal and vertical voltages. The outputs of the amplifiers are attached to the terminals shown in the diagram for subsequent application to the deflection system.

Time Base or Sweep Circuits

When the oscilloscope is used to observe waveforms, it is necessary to sweep the beam across the screen in a horizontal direction with a motion which varies linearly with time; that is, the beam must travel equal distances in equal lengths of time. In this type of motion, the beam moves across the screen from left to right with constant speed and then very quickly swings back to the left to begin another sweep. The sweep voltage used to secure this motion is a sawtooth waveform similar to that shown in figure 3–6.

During the time T_1 on the graph, the rising voltage sweeps the beam across the screen at a comparatively slow rate. During the time T_2, called the fly-back time, the beam is quickly returned to the starting point in preparation for

the next linear sweep. The motion of the beam is very swift during fly-back, and little or no visible trace is produced. In some oscilloscopes, a negative voltage is applied to the C–R control grid during fly-back to cut off the beam, thus eliminating all return trace entirely.

The figure which results from the simultaneous application

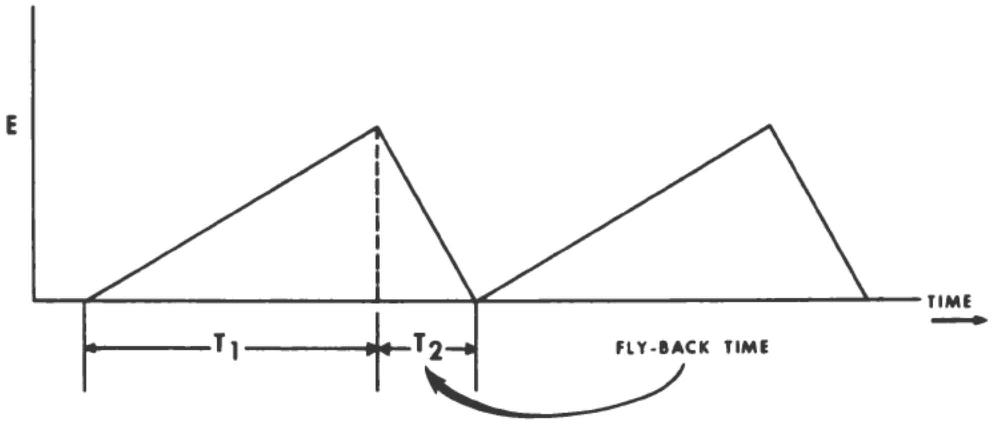


Figure 3–6.—Sawtooth wave used for horizontal sweep.

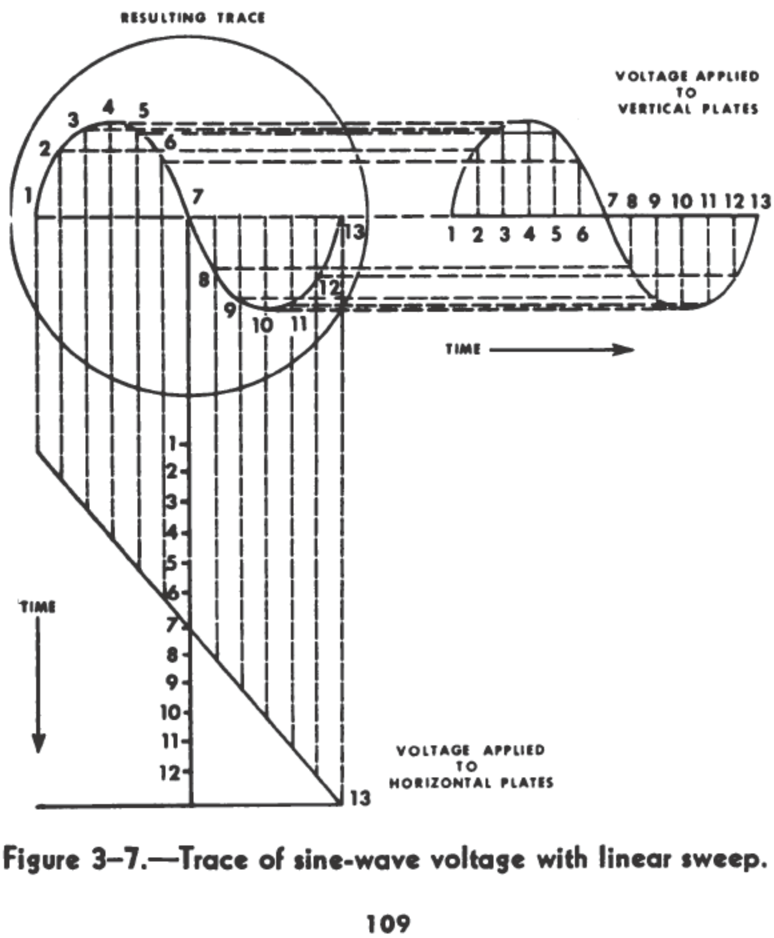


Figure 3–7.—Trace of sine-wave voltage with linear sweep.

of a sine-wave voltage to the vertical plates and a sawtooth voltage to the horizontal plates is shown in figure 3–7.

For each value of sawtooth voltage, there is a corresponding horizontal position of the beam. The sine wave causes the beam to be deflected vertically, above and below the center line of the screen, by an amount proportional to the instantaneous voltage value. The combination of both deflections produces the trace shown in the figure.

The simplest type of circuit for generating sawtooth waves is the gas-tube oscillator shown in figure 3–8.

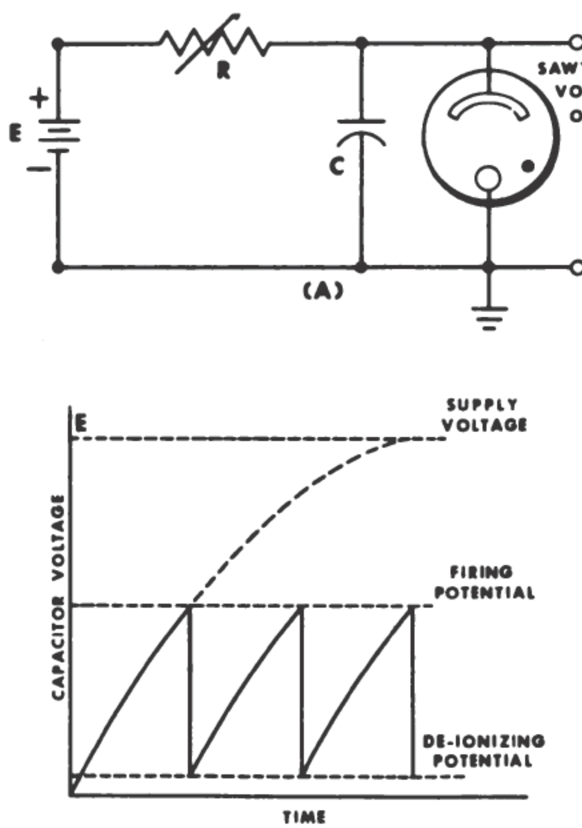


Figure 3–8.—Simple sawtooth generator.

The gas tube is a conductor with almost infinite impedance until the applied voltage reaches a value great enough to ionize the gas contained in the tube. Once ionized, a very small voltage is sufficient to keep the current flowing in the tube; and until the plate voltage falls below the value re-

quired to maintain ionization, the tube has a low impedance. When the voltage across the tube falls below the critical value, the gas de-ionizes and current flow ceases. The potential at which the gas ionizes and conduction begins is called the firing potential of the tube; and the voltage at which de-ionization takes place is called the de-ionizing potential. The gas tube is similar to a switch which is closed during ionization and open when the gas is de-ionized.

The sawtooth generator shown in the figure consists of a capacitor, a variable resistor, a source of d-c voltage, and the gas-tube switch. The voltage across the capacitor is controlled by the gas tube. The applied d-c voltage charges the capacitor through the resistor, causing the capacitor voltage to rise from zero as shown in (B) of figure 3–8 and approach the supply voltage along the normal R–C charging curve. The gas tube acts as an open switch until the voltage across it reaches the firing point. At this time the tube ionizes and forms a discharge path for the capacitor. The capacitor discharges very rapidly through the tube until the tube voltage falls to the de-ionizing potential; then conduction through the tube stops, and the tube becomes an open switch. The capacitor then begins to charge again toward the supply voltage with its voltage rising along the R–C curve until the firing potential of the tube is again reached. This process continues as long as the d-c supply is maintained.

The frequency of the sawtooth wave can be varied by changing the value of the resistor, the value of the capacitor, or the values of both. The resistor and capacitor form a time-constant circuit, and an increase in the value of either element increases the time required for a given amount of voltage to be developed across the capacitor and hence across the tube. A lower frequency is generated in the circuit when either the capacitance or resistance is increased in value; and a higher frequency results when the value of either is lowered.

In (A) of figure 3–9 is shown a thyratron tube circuit which is similar in principle to the gas-tube oscillator except

that a grid has been provided to control the firing potential of the tube. The higher the negative voltage of the grid (with respect to the cathode), the higher the firing potential of the tube. The de-ionizing potential is affected very slightly by the grid bias.

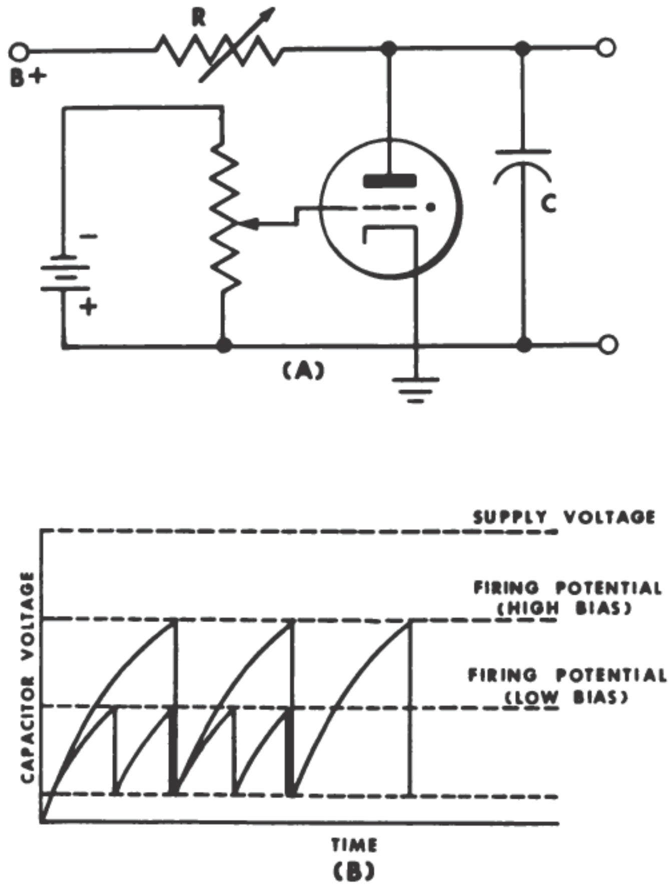


Figure 3–9.—Thyratron sawtooth oscillator circuit.

The graph in (B) of figure 3–9 shows the effects of varying the bias on the grid. With a large negative bias, the firing potential is high, and a comparatively long time elapses before the tube fires and discharges the capacitor. In this condition, the output frequency is low while the peak amplitude of the sawtooth wave is high. When the bias is lowered, the resulting low firing potential causes the capacitor to be charged and discharged rapidly, producing a higher frequency with lower peak amplitude in the output wave.

It is seen in the graph in (B) that the rise in voltage of the

sawtooth wave is not linear but follows the exponential charging curve of the capacitor. However, the lower portion of the curve is almost linear; and by using a d-c supply voltage that is large compared with the firing potential, a sawtooth wave that is sufficiently linear for most purposes can be obtained at the output of the circuit.

Synchronizing the Sweep Oscillator

In order to present a stationary pattern on the screen of the oscilloscope, the frequency of the sawtooth sweep voltage must either be equal to the frequency of the wave to be observed, or the two frequencies must have a ratio which is a whole number. When the sweep frequency is not related in this way to the observed frequency, the pattern appears to drift across the screen. The process by which the sweep frequency is adjusted to conform to that of the observed wave is called synchronization.

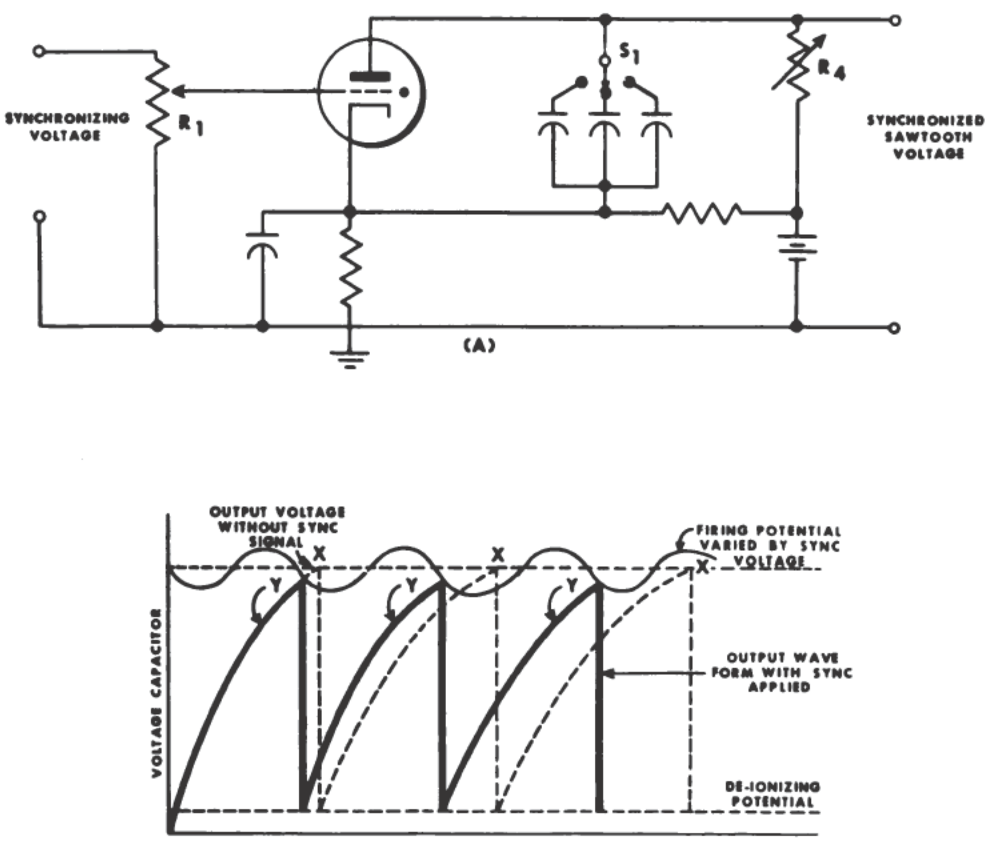


Figure 3–10.—Thyratron oscillator with provision for synchronization.

In (A) of figure 3–10, a thyratron oscillator circuit is shown in which a portion of the waveform to be observed is applied to the grid by means of the potentiometer, R_1. The voltage applied to the grid is called the synchronizing voltage.

The natural frequency of the circuit, which is to be modified by the synchronizing voltage, is adjusted by means of switch S1 and resistor R_4. One of the capacitors is selected by the switch, the coarse frequency control, to combine with R_4, the fine frequency control. The combination is an R–C frequency-selective circuit.

The natural frequency is adjusted first to a value slightly lower than the frequency of the waveform to be displayed. When the sync signal is applied to the grid, the firing potential of the tube is raised and lowered at the signal frequency as shown in the graph in (B) of figure 3–10. The action of the oscillator without synchronizing voltage is represented in the dotted curves, in which the tube fires at point X. Application of the sync signal causes the firing potential to assume a low value once during each cycle and the tube fires at point Y, thereby reducing the time required to complete each cycle and locking the oscillator frequency to the signal frequency. In a similar way, the oscillator can be synchronized to a multiple or submultiple of the signal voltage frequency.

Many times it is desired to observe more than one cycle of the signal waveform. To do this, the sweep must then be synchronized at some frequency lower than the signal. If two cycles are to be displayed, the sweep frequency must be exactly one-half the signal frequency. It must be one-third the signal frequency if three complete cycles are to appear on the screen.

In using an oscilloscope, the synchronizing signal control should be turned first to zero and the frequency of the sweep then adjusted to give maximum stability of the pattern on the screen. The synchronizing control is tnen given the minimum setting which causes the pattern to remain stationary.

Since the waveforms usually observed in electrical and electronic circuits are voltage variations, the electrostatic cathode-ray tube is generally employed in test oscilloscopes. The electromagnetic cathode-ray tube is a current operated device and is used for certain applications other than general testing.

When observing waveforms, several precautions must be observed. For the protection of both the operator and the instrument, the approximate amplitude of the voltages in the circuit under test should be known. In some cases, it may be necessary to observe waveforms in circuits which contain voltages much greater than the components within the oscilloscope can withstand. In these instances a voltage divider may be used to reduce the voltage applied to the input terminals to a value that will not damage the instrument.

As a protection for the operator, it is very important that the oscilloscope be adequately grounded, since failure of some part of the voltage divider can raise the voltage of the whole device to a dangerous level if the case is not at ground potential. If the voltage divider used is a capacitance divider, it is wise to parallel each capacitor with a high resistance in order to maintain the proper voltage distribution across the elements of the divider.

The input connections of most oscilloscopes consist of binding posts on the front panel of the instrument. The input circuit usually contains a coupling capacitor for passing alternating voltages and blocking direct potentials. The capacitors used seldom have voltage ratings greater than 450 volts, and application of excessive input voltages can result in voltage breakdown of the capacitor.

In order to avoid pickup of stray signals, the input leads from the circuit under test should be as short as possible. In addition, the ground terminal of the oscilloscope should be attached to a good external ground. The use of shielded cable for test leads aids in minimizing pickup of stray fields.

For additional coverage of the basic principles of the oscilloscope as a test device frequently used by the AT, the reader is referred to *Basic Electronics*, NavPers 10087, chapter 13.

Frequency Comparison

Measurement of frequency can be accomplished with the oscilloscope by comparing an unknown frequency with a standard, known frequency. The procedure involves the production of Lissajous patterns on the oscilloscope. These patterns, or figures, are traced on the screen when the linear sweep voltage is switched off and sine-wave voltages are applied both to the horizontal and to the vertical deflection plates.

The development of a typical Lissajous pattern is shown in figure 3–11. In the figure, the frequency of the signal applied to the vertical plates is twice that applied to the horizontal plates, giving a frequency ratio of 1:2.

In the patterns shown, the figure changes in appearance with changes in the phase angle of the two voltages. However, one fact is common to all. The number of times the patterns touch a horizontal line drawn along the top of the figures is two in each case. Also, the patterns all touch a vertical tangent line one time. The number of points of tangency to such horizontal and vertical lines indicates the ratio of the two frequencies. The relation of the frequency ratio to the pattern may be stated as follows:

$$\frac{\text{Frequency applied to horizontal plates}}{\text{Frequency applied to vertical plates}} = \frac{\text{Number of points of tangency to a vertical line}}{\text{Number of points of tangency to a horizontal line}}$$

In figure 3–12, the pattern touches the horizontal line, A–A, three times. It touches the vertical line, B–B, two times. Hence the ratio of the applied frequencies is 2:3. If one of the frequencies is known, the other can be found.

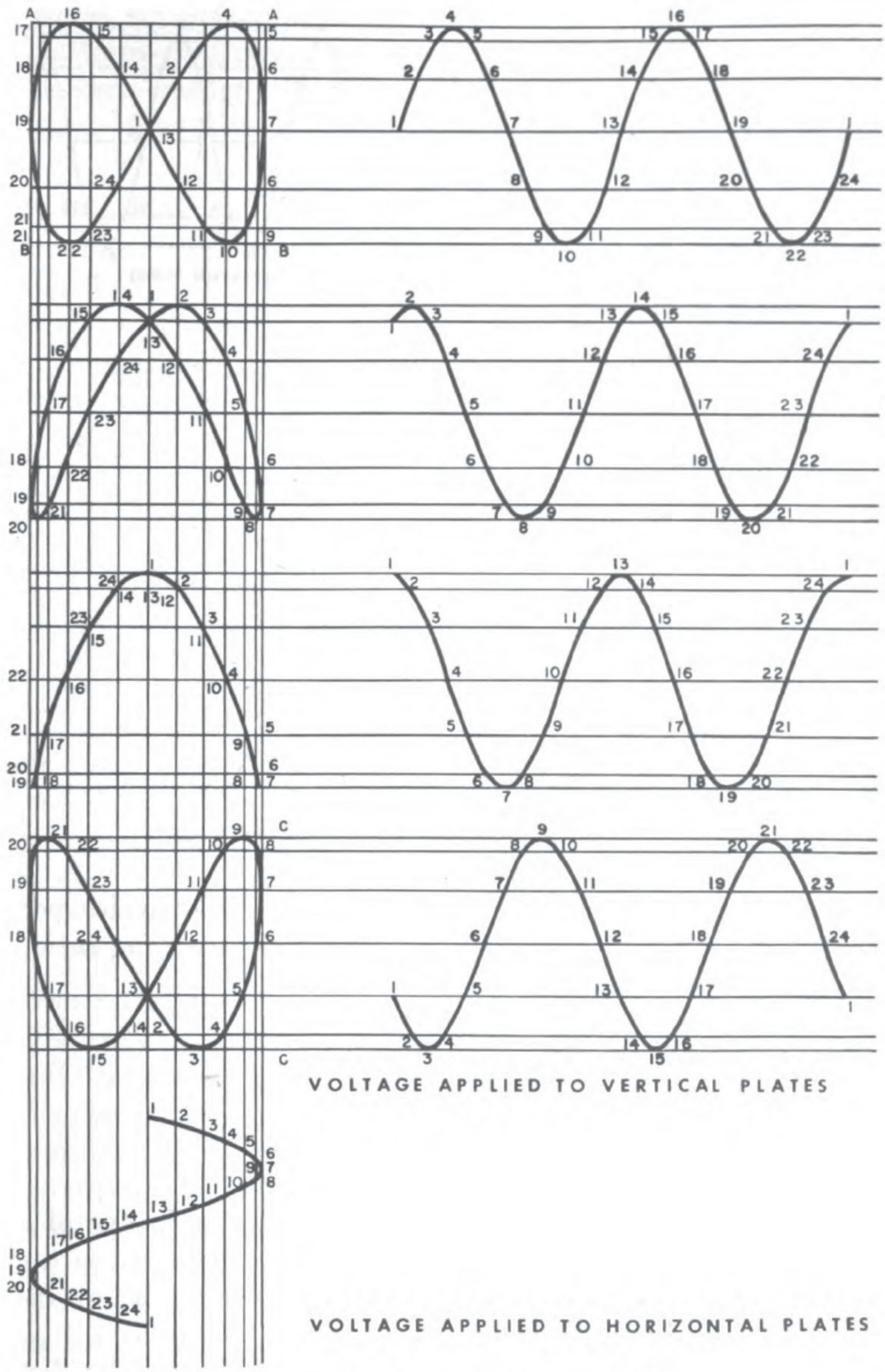


Figure 3–11.—Lissajous figures for 1:2 ratio.

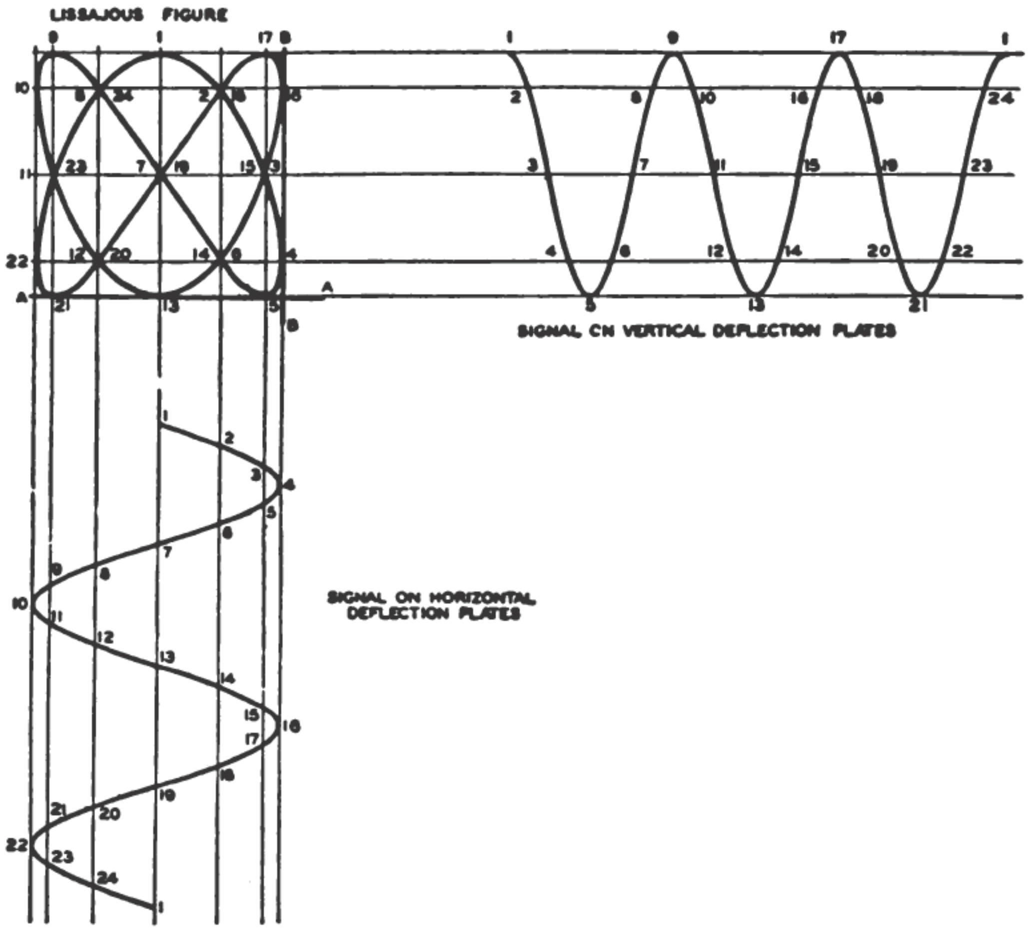


Figure 3–12.—Lissajous figure for 2 : 3 frequency ratio.

For example, if the horizontal frequency is 600 cycles per second, the vertical frequency can be found from the ratio, as follows:

$$\frac{600}{f}=\frac{2}{3}$$

$$f=\frac{3}{2}\times 600$$

$$f=900 \text{ cycles per second}$$

In measurement of unknown frequencies, the output of a calibrated oscillator or signal generator can be used as the standard frequency and comparison made with it by means of the oscilloscope figure.

In figure 3–13, the patterns resulting from various frequency ratios are shown. The circle is the simplest of Lissajous figures, and results when the applied frequencies are

equal and differ in phase by either 90 or 270 degrees. In patterns of frequencies which are almost equal, the traces become rather complex. Also patterns of ratios greater than 10 to 1 are difficult to interpret.

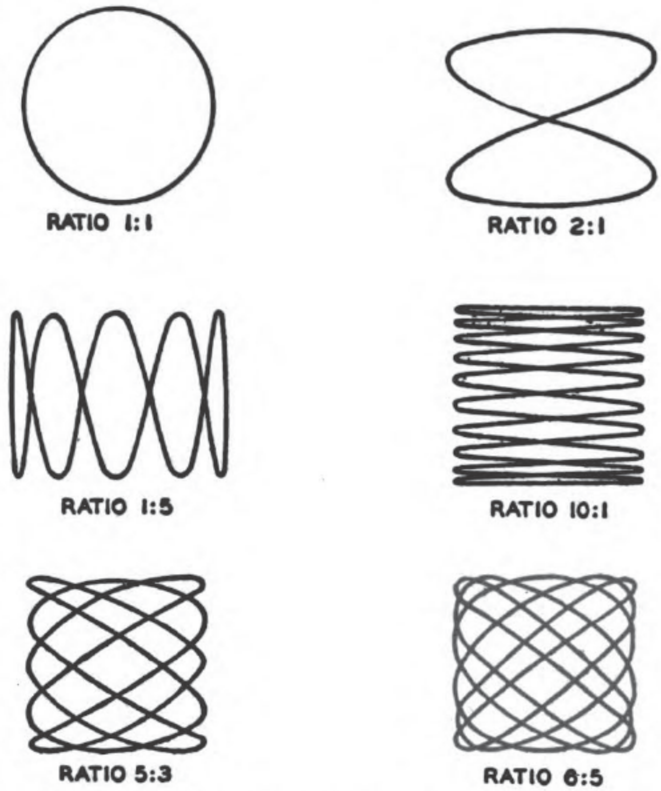


Figure 3–13.—Lissajous patterns for various ratios.

The general principles explained in the text, *Basic Electronics,* together with the methods of frequency measurement discussed here, are often used by the AT in checking the calibration of audio signal generators and low-frequency oscillators in receivers and test equipment. An interesting application is sometimes made by operators of airborne countermeasures equipment such as the AN/APA–11 pulse analyzer in measurements of pulse repetition frequencies of enemy radar sets. Enemy radar signals are intercepted by a search receiver (such as the AN/APR–4 unit). The receiver amplifies and detects the signals and produces a series of video voltage variations at the output. These are applied to the vertical deflection plates of the pulse analyzer which is used in this application as an airborne oscilloscope. The

output of a calibrated audio signal generator is applied to the horizontal deflection system of the oscilloscope. The horizontal sweep signal is then adjusted in frequency until a pattern consisting of a single trace appears on the screen. The pulse repetition frequency of the radar signal is then obtained from the value of the sweep voltage which can be read from the calibrated dial of the audio generator.

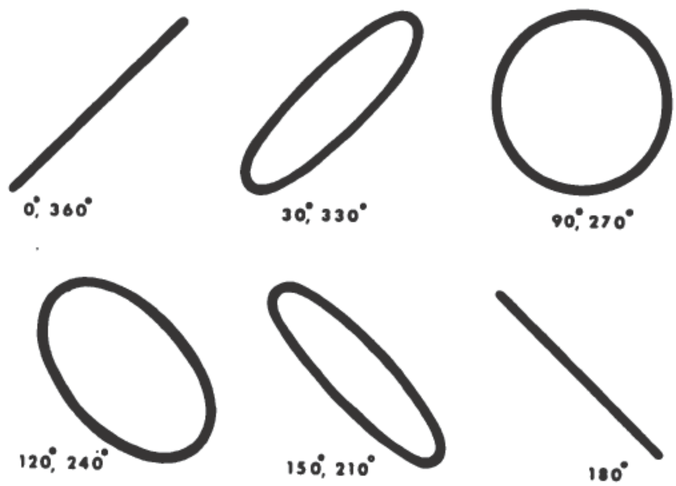


Figure 3–14.—Oscilloscope patterns which indicate phase difference.

In figure 3–14, the figures are indications of phase difference. If the applied frequencies are equal and in phase, the trace is a straight line tilted at 45 degrees. When the phase angle is increased, the line opens into an ellipse, or oval; and at exactly 90 (or 270) degrees, a circle appears. At 180 degrees of phase difference, a straight line is formed which is tilted at 135 degrees. In the patterns shown, the applied signals are of equal amplitude. If the voltages are not equal, the pattern never becomes circular, but is elliptical for angles different from zero or 180 degrees.

Amplitude Modulation Measurements

Chapter 8 of *Basic Electronics*, NavPers 10087, contains a discussion of the nature of amplitude-modulated waves, together with the methods by which they are produced in transmitting circuits. The following section is concerned

with methods which are often employed by the AT in measuring the percentage of modulation by means of the oscilloscope.

The oscilloscope provides a means of viewing and measuring the properties of amplitude-modulated waves in the output of transmitters. Several methods of checking modulation are possible. The simplest procedure is observation of a wave-envelope. The method of coupling and the resulting pattern are shown in figure 3–15.

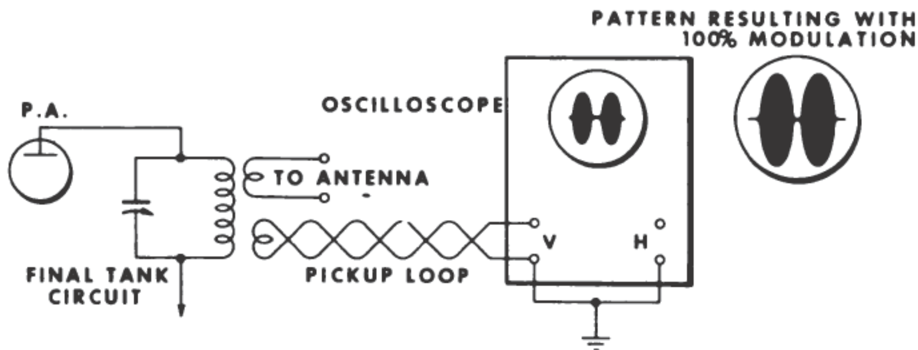


Figure 3–15.—Wave-envelope pattern of modulated wave.

A portion of the output from the amplitude-modulated transmitter is loosely coupled to the vertical deflection plates of the oscilloscope. It is necessary to couple the r-f voltage directly to the deflection plates without putting it through the oscilloscope amplifiers. A few turns of wire forming a pickup loop placed near the tank coil of the final amplifier of the transmitter provide sufficient voltage. Care should be taken to avoid making direct connections to points of high voltage in the transmitter. The internal sweep of the oscilloscope is turned on, and the modulated pattern results.

An accurate method for measuring the percentage of modulation is provided in the use of the trapezoidal pattern.

The coupling arrangement shown in (A) of figure 3–16 is used to obtain the trapezoidal pattern. The modulated r-f carrier is loosely coupled to the vertical deflection plates, using direct, or unamplified, coupling.

The internal sweep oscillator in the oscilloscope is switched off, and a portion of the audio output of the modulator is coupled to the horizontal plates of the instrument. The audio

modulating voltage is applied through an R–C coupling circuit containing a voltage-dropping resistor which lowers the voltage to a level that can be handled safely by the oscilloscope. The audio voltage is usually obtained from the secondary winding of the modulation transformer.

With no carrier voltage and no audio output, the pattern developed on the screen is a point, or spot. An unmodulated carrier produces a vertical line, as in (C) of figure 3–16. Modulation percentages less than 100 produce patterns similar to the trapezoid shown in (D); and a triangle, shown in (E), results when the transmitter is modulated exactly 100 percent. Overmodulated waves give the type of pattern shown in (F) of the figure.

In (B), the length, *a*, is proportional to the maximum value of the modulated waves; and the length, *b*, is proportional to the minimum value. These lengths can be used to compute the percentage of modulation. The lengths are measured in any convenient unit—usually the number of squares of the grid on the oscilloscope screen. The percentage of modulation of the wave is then found by substitution of these values in the following formula:

$$\frac{a-b}{a+b}\times 100=\text{percentage of modulation}$$

For example, if the length, *a*, is equal to 10 squares on the oscilloscope, and the length, *b*, is equal to 2 squares, then the percentage of modulation is

$$\frac{10-2}{10+2}\times 100=66\frac{2}{3}\text{ percent}$$

The field of application of oscilloscopes is very broad, and the few examples given here can serve only as a brief introduction to some of the basic uses of the instrument. Proficiency in testing and troubleshooting by oscilloscope methods can be gained only by experience. In addition, it is necessary to study the manuals of instruction provided with each instrument since many are highly specialized and are designed for specific types of testing.

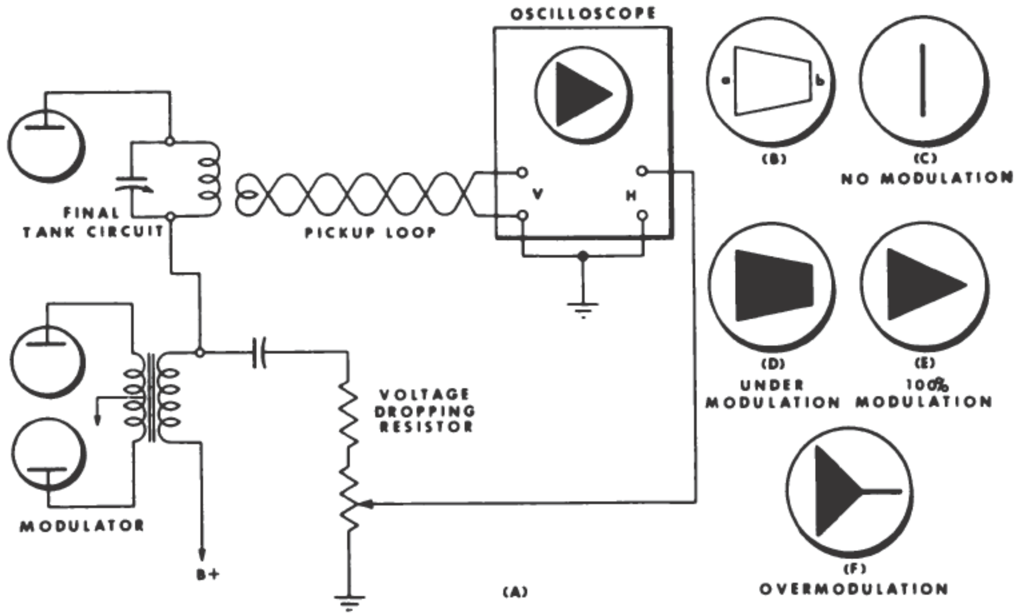


Figure 3-16.—Trapezoidal modulation patterns.

FREQUENCY METERS

This discussion of frequency meters supplements the section entitled "Frequency Standards" found in chapter 13 of *Basic Electronics*, NavPers 10087.

A frequency meter is an instrument which is used to provide a simple, reliable and accurate means for adjusting the emitted or resonant frequency of transmitters, field strength meters, receivers, and other tuned detectors or emitters to a desired value. The term FREQUENCY METER is sometimes applied to test instruments which measure the frequencies of external signals and have no provision for emitting a signal. This latter type of instrument is more properly called a WAVEMETER.

Thus, a frequency meter can be used as a signal generator which supplies a moderate and extremely accurate signal for the adjustment of receivers and other types of detectors to a desired frequency within its designed range, and as a wavemeter for determination and adjustment to frequency of transmitters and other types of emitters.

The heterodyne type of frequency meter which contains a reference crystal for more accurate calibration is fairly

typical. This type of instrument usually consists of a heterodyne oscillator, an r-f harmonic or distortion amplifier, a crystal-controlled oscillator, a mixer or detector, a modulator, an a-f output amplifier, and a means for indicating frequency (in most cases, a meter, or headphones). Most frequency meters are furnished with a set of calibration charts giving the dial readings for the frequencies listed, together with a table of the crystal harmonics; thus, a complete and accurate frequency coverage over the designed range is provided.

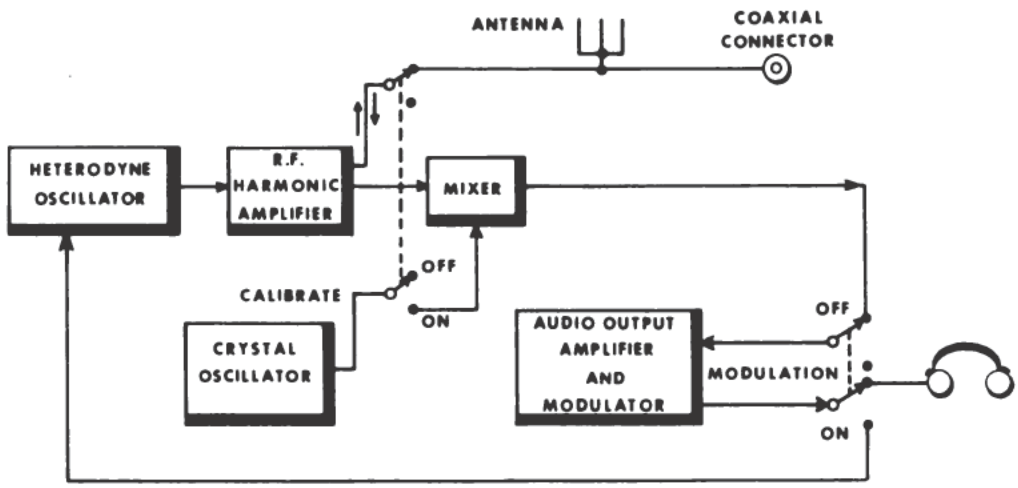


Figure 3–17.—Block diagram of typical heterodyne frequency meter.

In figure 3–17 is illustrated the block diagram of a typical heterodyne frequency meter.

In operation, the output of the variable frequency heterodyne oscillator is coupled into the r-f harmonic amplifier. When signals are being generated for receiver testing purposes, the output of this harmonic amplifier is coupled to the antenna and the r-f coupling connector as shown in figure 3–17. When the signals are being received as in transmitter testing, the harmonic amplifier output is coupled to the mixer (detector) tube along with the incoming signal under test.

The crystal-controlled oscillator operates at a fixed frequency, but is also capable of emitting various harmonic frequencies of the crystal for use as check frequencies (check

points) for adjusting the heterodyne oscillator, thus insuring more accurate operation. Provisions are usually made within the crystal-controlled oscillator for precise adjustment to its fundamental frequency. When it is desired to make this frequency check, comparison can be made to the standard WWV transmissions broadcast by the Bureau of Standards.

When the mixer is switched to the CALIBRATE position, the antenna and coaxial connector (r-f input) are disconnected and the heterodyne oscillator output is combined with the output of the crystal oscillator permitting the calibration, or correction, by the ZERO BEAT method of the variable oscillator on the desired frequency range. When the calibration switch is turned to the OFF position, signals from the antenna are coupled into the mixer along with signals from the heterodyne oscillator and the zero beat method is then used for the adjustment of the external transmitter under test.

With most frequency meters the audio amplifier has two functions. It amplifies the beat note produced by the mixing of the unknown signal and the calibrated heterodyne oscillator (modulation OFF), and thus gives a ZERO BEAT in the earphones when the signal of the equipment under test is adjusted to the frequency of the heterodyne oscillator. With the modulation switch in the ON position the stage serves as an audio-frequency modulator supplying an a-f signal and modulating the r-f signal produced by the heterodyne oscillator.

In figure 3–18 is illustrated a typical frequency meter in common use for the test and adjustment of aircraft electronic equipment operated in the frequency range of 20 to 450 megacycles. The chassis is shown removed from the carrying case. The calibration book necessary for accurate operation of the instrument is located in the open cover. This instrument is designed for either battery or auxiliary power supply operation. This, combined with its light weight and high accuracy, makes it easily adaptable for shop, line, or aircraft use.

The schematic wiring diagram of the TS–323/UR heterodyne frequency is shown in figure 3–19. As shown in the

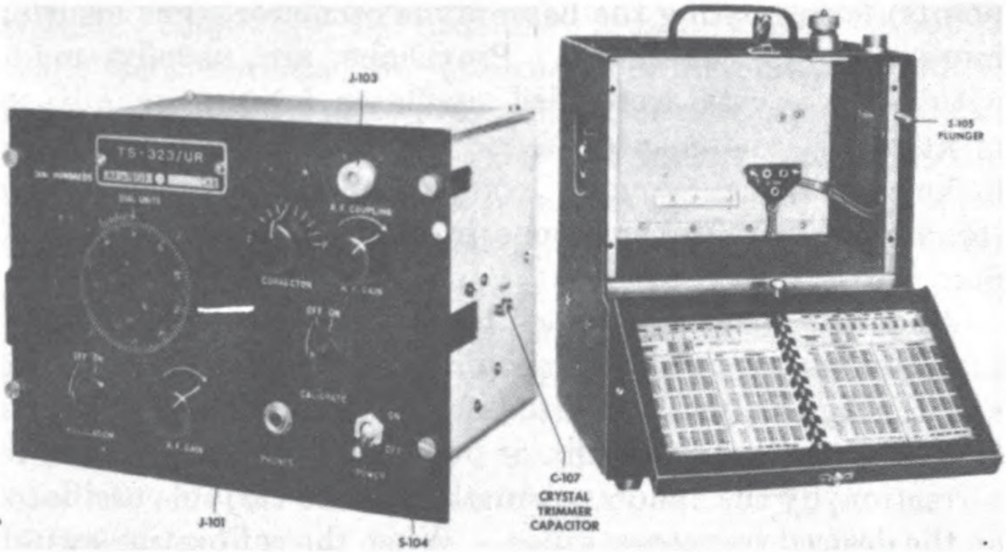
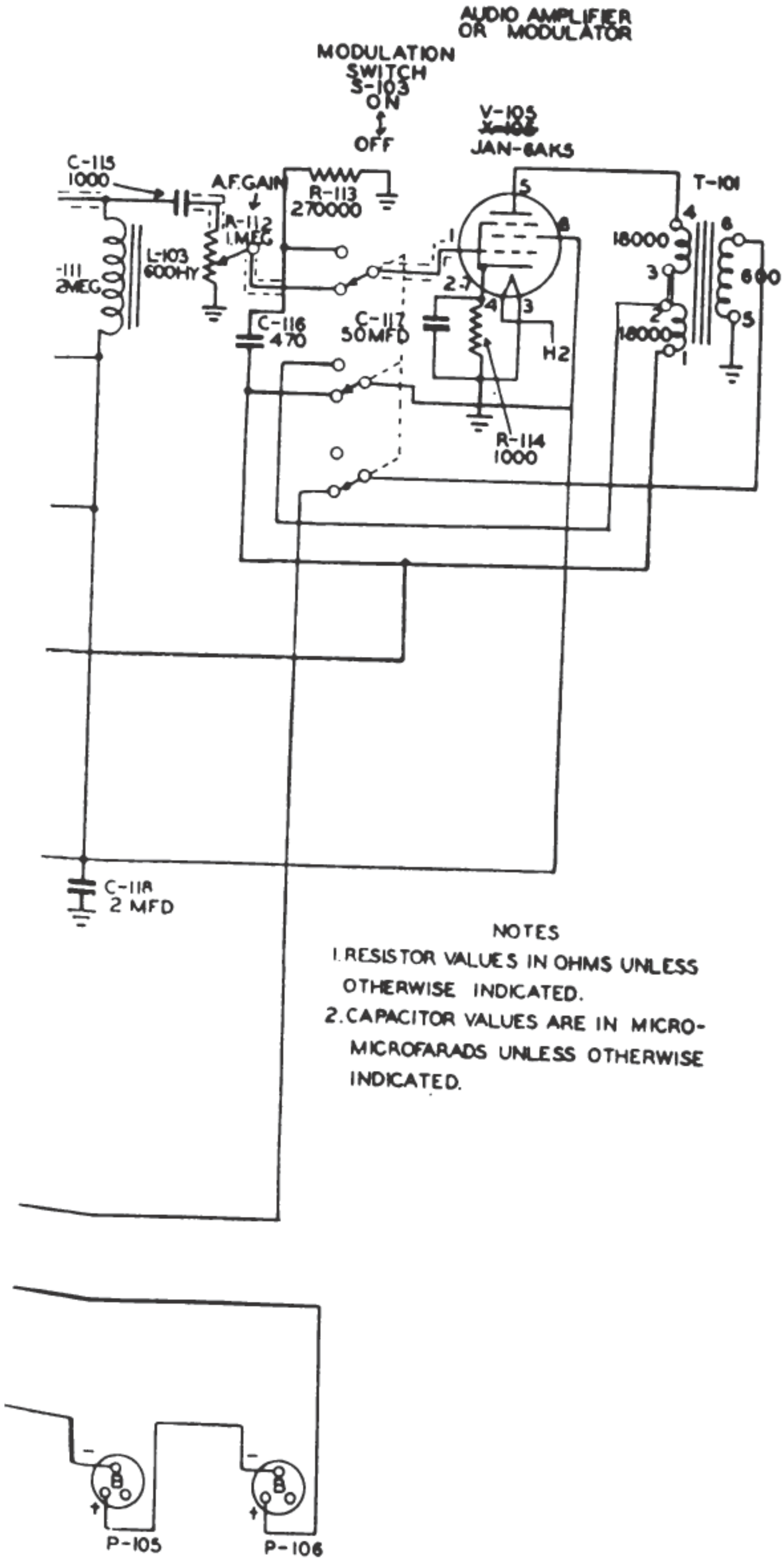


Figure 3–18.—TS–323/UR heterodyne frequency meter.

figure, the heterodyne oscillator utilizes a triode (V–101) in a modified Hartley circuit. The frequency determining elements are L–101, C–101, C–102, and C–103, all connected in parallel. C–101 is a corrector capacitor adjustable from the front panel by means of the CORRECTOR control knob and is used for correction of the oscillator frequency to that of the crystal oscillator. Trimmer capacitor C–102 allows internal correction adjustment beyond the range of the corrector capacitor (C–101). C–103 is the main tuning capacitor for tuning the heterodyne oscillator over a fundamental range from 20 to 40 mc. The remainder of the frequency range is obtained by use of harmonics up to the twelfth.

The r-f output from the heterodyne oscillator is coupled into the distortion or harmonic amplifier stage (through C–106) which contains a pentode tube, V–102. Some grid bias is obtained by means of R–102 which functions as a conventional grid leak, producing bias by means of the voltage drop from rectified grid current. Since no cathode bias is used and any positive signal applied to the grid is clipped, a new wave rich in harmonics results. The low value (47 ohms) of R–105, the plate-load resistance, is required to match the amplifier output to the impedance of the antenna coupling network.



NOTES

1. RESISTOR VALUES IN OHMS UNLESS OTHERWISE INDICATED.
2. CAPACITOR VALUES ARE IN MICRO-MICROFARADS UNLESS OTHERWISE INDICATED.

Capacitor C–110 couples the output from the r-f distortion amplifier into the antenna coupling network, or couples the antenna coupling network through capacitor C–111 to the control grid of the mixer (V–104), depending on whether the frequency meter is being used to generate or to receive signals. The antenna coupling network consists of a short length of 50-ohm coaxial cable and a 500-ohm potentiometer (R–104) which is the r-f gain control. It is adjustable on the front panel. Since only one of the output connections (antenna or coaxial cable connector J–103) will be used at a time, they are both wired directly to the arm of the r-f gain control potentiometer.

The triode, V–103, is connected in a conventional crystal oscillator circuit operating at a fixed frequency of 1,000 kilocycles. C–107 is a trimmer capacitor for the quartz crystal and provides an internal adjustment for setting the crystal frequency very close to 1,000 kilocycles. Grid leak bias is obtained through R–103. C–108 increases the effective grid-cathode capacitance of V–103 to an optimum value required for the crystal and crystal holder. R–108 is a voltage-dropping resistor connected so that V–103 will not oscillate when the calibrate switch, S–101, is in the OFF position. This resistor allows V–103 to draw plate current without oscillating, thus keeping a constant load on the "B" batteries for both positions of the calibrate switch. Improved plate voltage regulation is thereby obtained.

The necessary plate-load impedance for the oscillator is obtained from the untuned plate inductance L–102. Since the plate circuit is untuned, nonresonant effects are present and many harmonics of the fundamental crystal frequency are generated which provides several crystal check points for calibrating the heterodyne oscillator. With the calibrate switch ON, the output from the crystal oscillator is coupled into the heterodyne mixer grid circuit through limiting resistor R–109 and coupling capacitor C–112. This coupling arrangement prevents overloading the mixer with a strong signal from the crystal oscillator.

A pentode, V–104, is used as a mixer. The voltage developed across the r-f harmonic amplifier plate-load

resistor R–105 is coupled into the control grid of the mixer through a small fixed capacitor, C–111. With the calibrate switch OFF as shown and the crystal oscillator disabled, signals from the antenna coupling network are also coupled into the grid circuit of the mixer through capacitors C–110 and C–111. With the calibrate switch ON, the mixer combines the heterodyne oscillator output with crystal oscillator output for calibration purposes. This also disconnects the antenna coupling network from the instrument, thus preventing the generation of spurious beat notes that might be caused from external signals picked up by the antenna. The audio beat-frequency (difference) voltage resulting from the combined r-f signals at the control grid appears across the plate-load inductance L–103. This a-f signal is coupled through capacitor C–115 to the grid of the audio output amplifier.

The pentode, V–105, is either an audio output amplifier or a modulator, depending upon the position of the modulation switch S–103. With the modulation switch OFF, this stage functions as an audio amplifier. The mixer output is coupled through C–115 to the grid circuit of V–105. The potentiometer R–112 controls the input to the stage through the front panel a-f gain control adjustment. Cathode resistor R–114 supplies proper bias for class A operation. The output of V–105 is fed into the primary winding of T–101. The winding ratio of this transformer is such that the tube output impedance is properly matched with a 600-ohm load.

With the modulation switch ON, V–105 functions as an audio-frequency modulator with the grid connected to coupling capacitor C–116. This capacitor also serves as a blocking capacitor for direct current and R–113 provides a grid return to cathode. The auxiliary winding (terminals 1 and 2) is inductively coupled to the plate winding (terminals 3 and 4) thus permitting the stage to oscillate at about 1,000 cycles. The second section of the modulate switch S–103 connects the B+ of the heterodyne oscillator in series with the auxiliary winding of T–101 with the result that the plate circuit of the oscillator is

modulated at an audio-frequency rate. The third section of the modulation switch disconnects the secondary winding of the output transformer from the phone jack so that the a-f modulator output will not be heard in the headphones.

The power input circuit is wired so that either internal batteries or an external power supply may be utilized through the use of the D. P. D. T. switch S–104. J–105 is the external power input plug wired to the power changeover switch S–104. J–104 is a female battery power receptacle located in the frequency meter carrying case. P–101 is the corresponding male plug mounted on the back of the frequency meter chassis so that it will plug into J–104 when the chassis is put into the carrying case.

Two 6-volt "A" batteries connected to P–102 and P–103 (in parallel) and three 45-volt "B" batteries connected to P–104, P–105, and P–106 (in series) are required for battery operation. A total B+ voltage of 141 volts is obtained (pin 1 of P–101) by connecting the "B" battery supply (135 volts) in series with the "A" battery supply (6 volts). The batteries are stowed in the carrying case beneath the chassis and are accessible along with spare parts for the instrument from the back of the carrying case.

Switch S–102 is the power switch located on the control panel. This switch has three positions, STANDBY, OFF and OPERATE. In the STANDBY position filament voltage is impressed only on the heterodyne oscillator, V–101, thus limiting current drain during the warmup period. C–118 and C–119 are bypass capacitors providing a low impedance path across the power supply which reduces the common coupling between the various frequency meter circuit components. S–105 is a spring action plunger type switch mounted so that the plunger is actuated by the operating controls compartment cover. Closing the cover pushes the plunger in and disconnects the A+ lead and B– connection from the frequency meter which prevents leaving the power on when the frequency meter is not in use.

SIGNAL GENERATORS

In the maintenance of airborne electronic equipment, it is often necessary to employ standard sources of a-c energy, both audio-frequency and radio-frequency. These sources are called SIGNAL GENERATORS. They are used in testing and alinement of radio receivers and amplifiers, in trouble-shooting various electronic devices, and sometimes for measurement of frequency.

The principal function of a signal generator is the production of an alternating voltage of the desired frequency and amplitude which has the necessary modulation for the test or measurement in question. It is very important that the amplitude of the generated signal be correct, and in many generators, output meters are included in the equipment so that the output may be adjusted and maintained at a standard level over a wide range of frequencies.

When using the generator, the output test signal is coupled into the circuit being tested and its progress through the equipment is traced by the use of high-impedance indicating devices such as vacuum-tube voltmeters or oscilloscopes. In many signal generators, calibrated networks of resistors, called ATTENUATORS, are provided. These are used to regulate the voltage of the output signal and also provide correct impedance values for matching the input impedance of the circuit under test. Accurately calibrated attenuators are desirable since the signal strength must be regulated to avoid overloading the circuit receiving the signal.

There are many types of signal generators. It is possible to classify them roughly by frequency into audio generators, generators of both the audio and video ranges, radio-frequency generators, frequency-modulated r-f generators, and special types which combine all of these frequency ranges.

In almost all of these types, electron tube oscillators are used to produce the initial signal. In order to achieve accurate results in the use of the signal source, it is necessary to allow the oscillator circuits to reach a condition of stable

operation before applying the output. This condition is reached when the tubes and circuit elements attain the temperature at which the instrument was calibrated. A preliminary warmup should always be given the generator when accurate and stable signals are desired. The minimum warmup time for the generator is contained in the *Handbook of Service Instructions*. The general properties and functions of signal generators were covered in *Basic Electronics*. In the sections immediately following, there is a discussion of the types of generators most commonly used by the Aviation Electronics Technician.

Audio and Video Signal Generators

Audio signal generators produce stable audio-frequency signals used for testing audio equipment. Video signal generators produce signals which include the audio range and extend considerably further into the r-f range. These generators are used in testing video amplifiers and other wide-band circuits. In both audio and video generators, the major components include a power supply, an oscillator (or oscillators), one or more amplifiers, and an output control. Voltage regulation circuits are necessary to insure stability of the oscillator in generators which derive power from 115-volt, a-c sources. In portable generators, battery power supplies are usually used and these require no voltage regulation.

In audio and video generators of the beat-frequency type the output frequency is produced by mixing the signals of two radio-frequency oscillators, one of which is fixed in frequency and the other variable. The difference in frequency of the two is equal to the desired audio or video frequency. For example, if the fixed and variable oscillators both produce a frequency of 400 kilocycles, the resultant output frequency is zero cycles. If the variable oscillator is changed to 401 kilocycles, the resultant is then 1 kilocycle. By action of this type, any desired frequency in the range of the circuits may be produced in the output.

Audio signal generators often include R–C oscillators in

which the audio frequency is directly produced. In these, a resistance-capacitance circuit is the frequency determining part of the oscillator. The frequency varies when either the resistance or the capacitance is changed in value. In commercial generators, however, the capacitance alone is often chosen as the variable element. The change in frequency which can be produced by this method is limited and it is usually necessary to cover the entire range of the generator in steps. This is accomplished by providing several R–C circuits, each corresponding to a portion of the entire range of frequency values. One of the circuits is switched in the oscillator at a time to give the desired portion of the audio range.

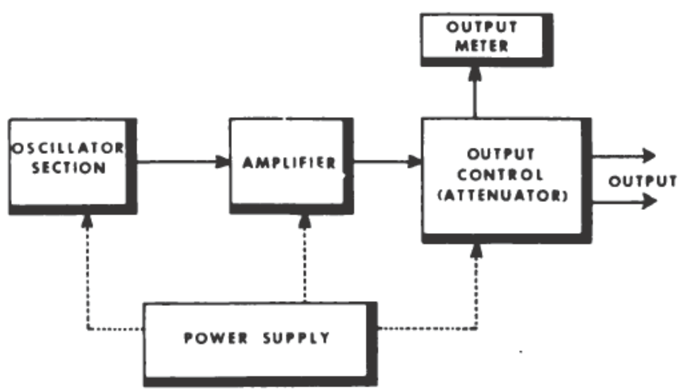


Figure 3–20.—Block diagram of typical audio or video signal generator.

The amplifier section of the block diagram of figure 3–20 usually consists of a voltage amplifier and one or two power amplifiers. These are coupled by means of R–C networks, and the output of the final power amplifier is often coupled to the attenuator, or output control, by means of an output transformer.

The output control section provides a means of matching the output signal to the input of the equipment under test and regulating the amplitude of the signal. The settings of the output control knob provide output voltage values which are either inscribed directly on the knob or which can be interpreted by reference to the instruction manual provided with the generator.

Radio-Frequency Signal Generators

A typical radio-frequency signal generator contains, in addition to the necessary power supply, three main sections: an oscillator circuit, a modulator, and an output control circuit. The internal modulator is usually a circuit which produces sine-wave modulation of the radio-frequency signal. In addition, most r-f generators are provided with connections through which an external source of modulation of any desired waveform may be applied to the generated signal. Metal shielding surrounds the unit to prevent signals from the oscillator from entering the circuit under test by means other than through the output circuit of the generator.

A block diagram of a typical r-f signal generator is shown in figure 3–21.

The function of the oscillator stage is to produce a signal which can be accurately set in frequency at any point in the range of the generator. The type of oscillator circuit used depends on the range of frequencies for which the generator is designed. In low-frequency signal generators, the resonating circuit consists of one of a group of coils combined with a variable capacitor. One of the coils is selected with a range selector switch which attaches it to the capacitor to provide an LC circuit which has the correct range of resonant frequencies.

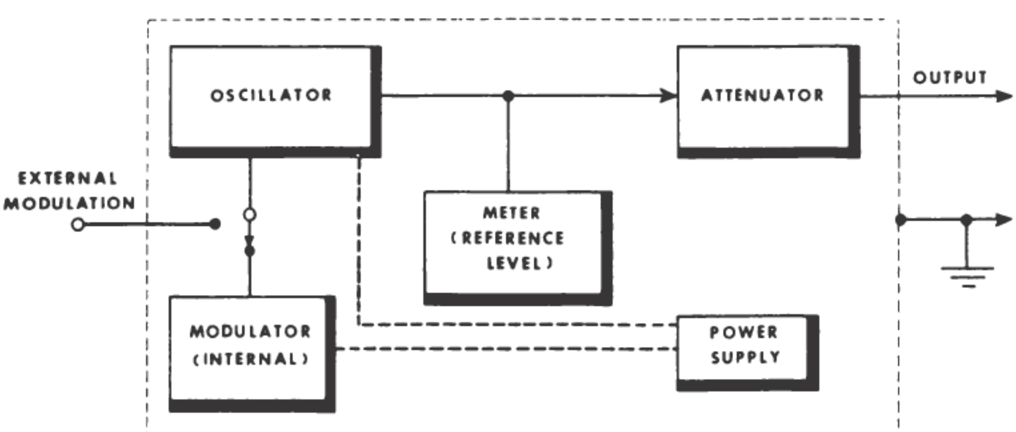


Figure 3–21.—Block diagram of a radio-frequency signal generator.

In signal generators designed for the higher frequencies, the resonating circuits are in the form of butterfly tuning circuits and resonant cavities. Reflex klystron oscillators are also used frequently in generators of frequencies above 1,000 megacycles.

In any signal generator, it is required that the oscillators have good stability both in frequency and amplitude over a wide range of output frequencies.

The function of the modulating circuit is the production of an audio (or video) voltage which can be superimposed on the r-f signal produced by the oscillator. The modulating signal may be provided by an audio oscillator within the generator (internal modulation), or it may be derived from an external source. In almost all signal generators, either of these methods of modulation may be employed. In addition a means of disabling the modulator section is used whereby the pure unmodulated signal from the oscillator can be used when it is desired. The type of modulation used depends on the application of the particular signal generator. The modulating voltage may be either a sine wave, a square wave, or pulses of varying duration. In some specialized generators, provision is made for pulse modulation in which the r-f signal can be pulsed over a wide range of repetition rates and at various pulse widths.

Usually the output circuit of the generator contains a calibrated attenuator and often an output level meter. The output level meter gives an indication of, and permits control of, the output voltage of the generator by indicating arbitrary values of output read in tenths through the value of one. The attenuator selects the amount of this output. The attenuator, a group of resistors forming a voltage-dropping circuit, is controlled by a knob which is often calibrated in microvolts. When the control element is adjusted so that the output meter reads unity (1.0), the reading on the attenuator knob gives the value of the output in microvolts. If output voltage is desired at a lower value, the control is varied until the meter indicates some decimal value less than one, and this decimal is multiplied by the attenuator reading to give the output in microvolts.

Frequency-modulated r-f signal generators are widely used for testing frequency-modulated receivers and for visual alinement (using an oscilloscope) of a-m receivers. A frequency-modulated signal is an alternating voltage in which the frequency varies periodically above and below a given center frequency value. The overall frequency change is called the frequency swing. This swing occurs at an audio-frequency rate.

There are several methods by which the frequency of the oscillator in the signal generator may be frequency-modulated. In one type of f-m generator, use is made of a vibrating plate which forms one of the elements of the tuning capacitor of the oscillator to be modulated. The plate is driven by a device similar to a magnetic loudspeaker. The audio modulating voltage is applied to the driving coil which moves in the field of a permanent magnet and vibrates the plate of the capacitor at the applied audio frequency. Movement of the plate causes variation of the capacitance in the oscillator tuning circuit with the result that the frequency of the oscillator is periodically raised or lowered.

Another method of producing frequency modulation is based on the action of a reactance tube which is connected in parallel with the tuning circuit of the oscillator to be modulated. A reactance tube is an electron tube in which the plate current is made either to lead or to lag the plate voltage variations by 90 degrees. Because of this phase difference, the plate circuit of the tube is electrically equivalent either to a capacitor or to an inductance. Audio voltage is impressed on the grid of the reactance tube, causing the capacitive (or inductive) reactance of the plate circuit of the tube to vary at an audio rate. Since the reactance tube plate circuit is a part of the oscillator tuning circuit, variation in the reactance value causes the generated frequency to vary in step with the audio modulating voltage.

In signal generators of microwave frequencies, frequency modulation is easily accomplished in the oscillator by applying the modulating audio voltage to the repeller plate of the reflex klystron tube which is usually employed in these generators.

SPECTRUM ANALYZERS

During the modulation of a radio-frequency carrier wave by keying, by speech or music, or by pulses, the resulting wave contains many frequencies. The original carrier is present together with two groups of new frequencies called the sideband components. One group of sidebands is displaced in frequency below the carrier. The other group is displaced above the carrier. The distribution of these frequencies when shown on a graph of voltage or power against frequency is called the SPECTRUM OF THE WAVE.

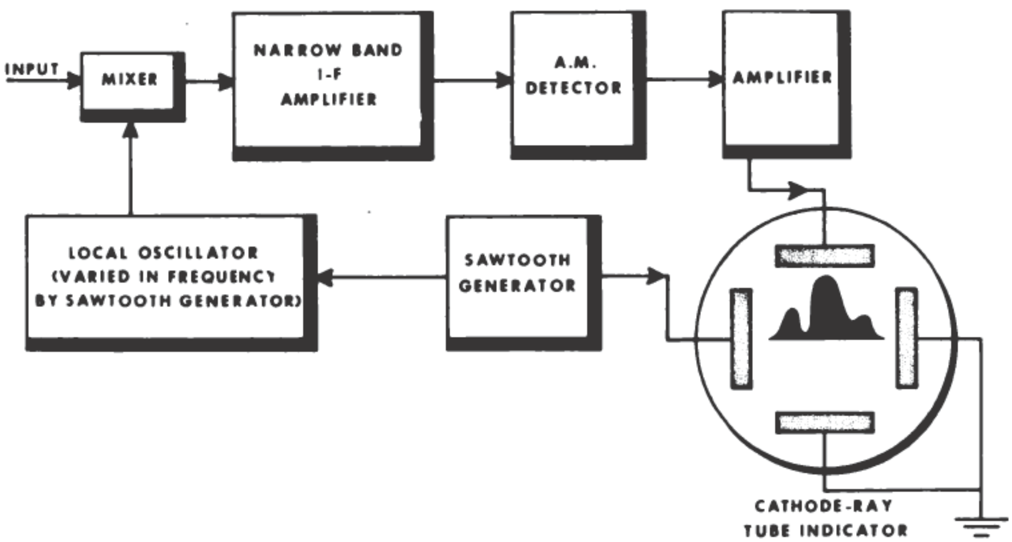


Figure 3–22.—Block diagram of spectrum analyzer.

A spectrum analyzer is a device for exhibiting the spectrum of modulated waves in the radio-frequency range and in the microwave region.

In principle, the spectrum analyzer operates by tuning through the frequency region in question using a narrow-band receiver. The output of the receiver is measured, usually by means of a cathode-ray oscilloscope, and the plot on the screen is a graph of voltage versus frequency.

The device is essentially a superheterodyne receiver with a very narrow-band intermediate-frequency amplifier section. The local oscillator frequency is varied between two values at a linear rate. The frequency-control generator which

governs the frequency of the local oscillator also produces the horizontal sweep voltage for the cathode-ray tube deflection plates. As a result, each position of the beam corresponds to a definite frequency value; and the display is a graph in which the X-axis is interpreted in terms of frequency.

The output of the detector in the receiver is amplified and applied to the vertical deflection plates so that the beam is deflected vertically by an amount proportional to the voltage developed in the detector (and amplifier).

The signal to be analyzed is fed into the mixer stage of the receiver. The local oscillator changes in frequency at a linear rate, beating with each of the signal frequency components in succession to form the intermediate frequency of the narrow-band amplifier. The output of the i-f amplifier is detected, amplified, and applied to the vertical deflecting plates.

Spectrum analyzers designed for analysis of microwave signals are equipped with klystron tubes in the local oscillator stage. In analyzers adapted for lower frequency r-f signals, triode oscillators are used which are varied by means of reactance-tube modulators.

Spectrum analyzers are employed extensively in studying the output of pulse radar transmitter tubes such as the magnetron. In this kind of analysis, unwanted effects such as frequency modulation of the carrier can be easily detected. In pure amplitude modulation of a carrier wave by a square pulse, the spectrum is symmetrical about the carrier frequency. Lack of symmetry indicates the presence of frequency modulation. A spectrum representing the ideal condition is shown in (A) of figure 3–23.

Examples of undesirable magnetron spectra are shown in (B) and (C) of figure 3–23. These forms indicate trouble in the modulator, the tuning system, or in the magnetron tube itself.

The carrier frequency is best defined as the center frequency in a symmetrical spectrum such as that shown in (A) of figure 3–23. In some analyzers this principle is used as a means of carrier frequency measurement. A sharply resonant circuit is provided in the receiver which acts as a trap to

Figure 3-23.—Frequency spectra.

prevent an extremely narrow range of frequencies from appearing in the output of the i-f amplifier. The result of its use is that a gap appears in the display and the gap corresponds to the resonant frequency of the trap. The adjustment of the trap is calibrated in frequency, and the circuit can be adjusted to make the gap occur in the center of the spectrum. The frequency of the carrier is then read from the calibration of the trap.

For an additional coverage of spectrum analyzers, the reader should consult *Basic Electronics*, NavPers 10087.

POWER ABSORPTION CONES

The primary purpose of a power absorption cone is to provide an absorbing shield for radar transmitting antennas to prevent radiation. By absorbing the r-f energy, reflections from nearby objects which cause erratic operation of the radar under test are thereby prevented.

A typical power absorption cone is illustrated in figure 3-24.

The cone consists of a pickup horn, shown at 1 of figure 3-23, mounted at the apex of a pyramid, 2. The pyramid is constructed in such a way as to absorb energy radiated from the system under test. The inner walls of the pyramid are lined with a material that has high absorbing qualities, so that the radiation that does not fall on the horn will be absorbed. Power picked up by the horn may be connected into an echo box or other test device.

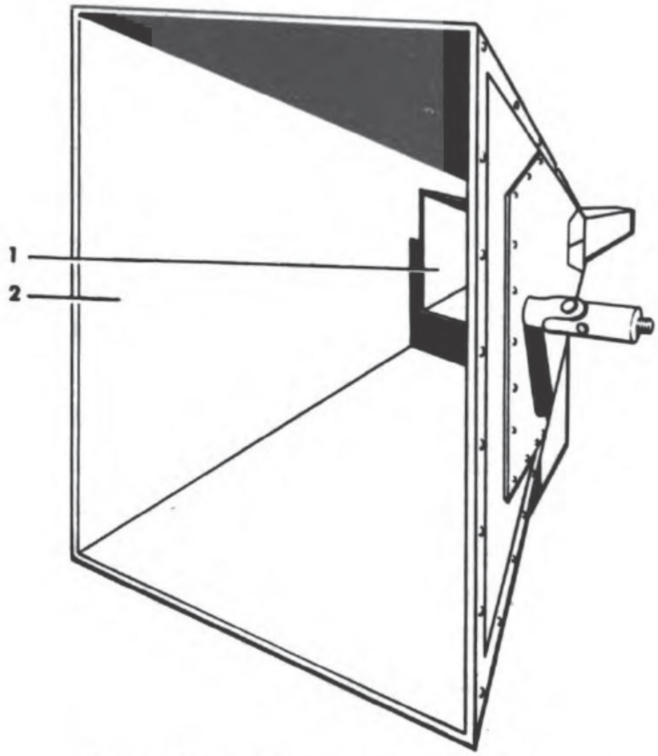


Figure 3–24.—Power absorption cone.

An absorbing screen is often used when it is desired to operate a radar in an enclosed space. The purpose of the absorbing screen is to absorb the radiated energy from the radar transmitter under test and this prevents high-power reflections from being returned to the radar system or to other radars. The screen usually consists of a number of straight expanded hard rubber panels and is mounted in front of the radiating antenna.

ECHO BOXES

An important part of the work of the AT consists in performing tests to determine the operating characteristics of airborne radar sets such as the AN/APS–33 series and AN/APS–20 sets. The following section is related to the general principles of radar operation as discussed in chapter 14 of *Basic Electronics*, and is a brief discussion of the use of a device which is often employed for making specific tests of the overall performance of a radar installation.

Under field conditions it is difficult to check the operation of radar equipment because of the absence of standard signals. The use of normal return signals is undesirable for purposes of adjustment and measurement because these signals vary considerably with atmospheric conditions and with the nature of the physical surroundings. A device which is frequently used to supply standard reference signals is the echo box.

An echo box is a tunable resonant cavity which has a very high Q. The cavity is equipped with coupling loops, either a dipole or a coaxial horn antenna, a crystal detector, a microammeter, and several sections of transmission line. The cavity is tuned by means of a movable plunger which is mechanically connected to a calibrated tuning dial. The echo box receives energy from the radar transmitter either by use of a pickup dipole (or horn) or by connection through a cable to a directional coupler in the transmission line of the radar set.

Echo boxes are used in measuring the overall performance of radar sets, in making spectrum graphs of magnetrons, for measuring the relative power output of radar transmitters, and for checking the frequency of the transmitter and of the local oscillator.

The basic circuit for making echo box tests is shown in the block diagram of figure 3–25.

In measuring the overall performance of radar sets, some of the energy generated by the radar transmitter is picked up by the directional coupler or by the pickup dipole and applied to the echo box. This energy excites oscillations in the echo box which persist for some time after the end of the radar pulse. These oscillations gradually die out because some of the power is radiated back to the radar set and the rest of it is dissipated in the echo box cavity and in the output meter circuit. The part of the energy that is fed back to the radar antenna causes a signal to appear on the radar indicator.

The time between the end of the transmitted pulse and the time when the returned energy from the echo box falls below the minimum value required to give an indication on the radar indicator is called the RINGING TIME. The ringing

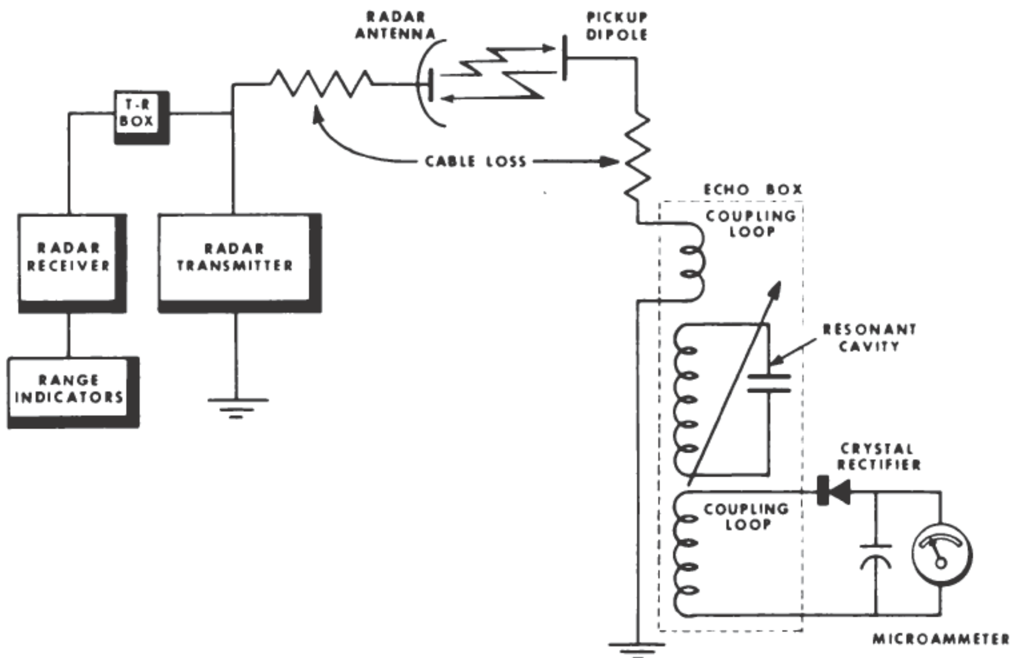


Figure 3–25.—Circuit for echo box tests.

time duration depends upon the power output of the transmitter and the sensitivity of the receiver. The longer the ringing time, the better is the overall performance of the system. Each radar set has a minimum performance ringing time and this value provides a standard for use in checking the operation of the set. The value of the minimum ringing time for a particular radar can be found in the appropriate manual of operating instructions.

Figure 3–26 illustrates three typical ringing time indications similar to those in overall performance checks made with echo boxes.

Echo boxes are often used in making spectrum graphs of transmitter output. Each time a radar transmitter generates an r-f pulse, it produces electromagnetic energy in the form of electromagnetic waves. Not all of these waves are of the same frequency. Some of the energy is radiated at the frequency to which the transmitter is tuned and the remainder is distributed in frequencies which are higher and lower than the tuned frequency. A spectrum graph showing the values of the frequencies present and their relative strength can be made by tuning the echo box across the

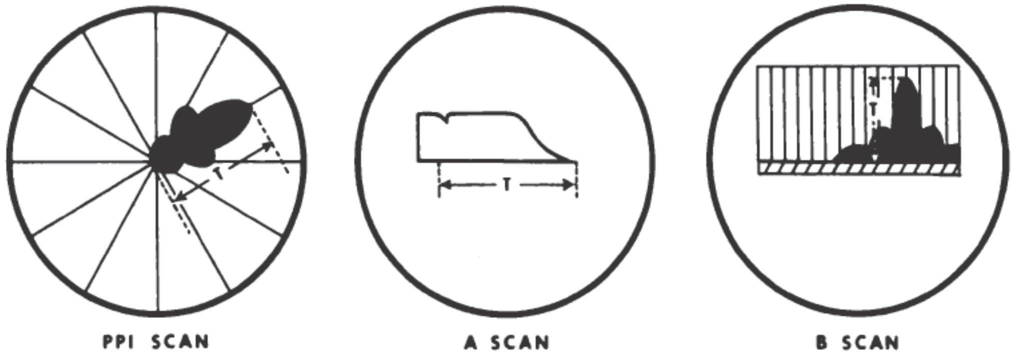


Figure 3–26.—Ringing time indications.

entire range of frequency-values in the output of the transmitter. The readings of the output meter in the echo box are plotted against frequency values in the spectrum which are read from the calibrated dial of the instrument. A radar transmitter in satisfactory condition gives a spectrum graph which is a peak with the sloping sides symmetrical and containing several smaller peaks separated by well-defined minimum values. A curve without well-defined minimum values indicates that the transmitter output is frequency-modulated during the pulse.

The echo box can be used to measure the relative power output of radar transmitters. The amount of energy delivered to the resonant cavity of the echo box depends on the average power of the radar pulse, the pulse length, the amount of loss in the directional coupler or pickup dipole, and the amount of loss in the connecting cables. The echo box is tuned to give a maximum reading of the output meter. The meter coupling circuit is then adjusted so that the maximum reading falls on the approximate center of the scale, and this value is recorded to be used as a reference. After adjustments on the transmitter are made, the readings of the echo box output meter are compared with the reference value to determine the effects of the adjustments on the output power.

Multiple moding, which is an abrupt and irregular jumping from one frequency to another, sometimes occurs in micro-

wave radar equipment. This effect is readily detected with the echo box. The indication of multiple moding is an erratic ringing time pattern containing several background noise traces in the pattern.

The transmitter frequency and the frequency of the receiver local oscillator can be measured by using the echo box as a wavemeter. In addition to these checks, the device can be used in measuring the signal-to-noise ratio, for testing the operation of the automatic frequency control, for measuring the T–R Box recovery time, the receiver recovery time, and the amount of loss in transmission lines. For these tests and measurements the instruction book for the particular echo box in use must be consulted.

FIELD STRENGTH METERS

In measuring the performance of antenna systems, the important quantities to be found are the radiated power, the directions in which the power is radiated, and the strength of the radiated wave. The radiated power can be measured in several ways, the simplest being based on the measurement of the antenna current and the antenna radiation resistance. The directions of maximum radiation and the strength of the radiated wave are found by field strength measurements.

The field strength of radio waves is measured in terms of the voltage induced by the wave in a receiving antenna. The unit of field strength is the volt-per-meter, but since the actual values of induced voltage are quite small, the microvolt-per-meter is a more convenient unit in practical applications.

In absolute field strength measurements, the exact amount of voltage induced in the receiving antenna must be found and the field strength is then derived from this value by application of an appropriate mathematical formula based on the type of receiving antenna employed. (Loops are generally used in low-frequency measurements.) The equipment used in absolute field strength measurements is rather complex and bulky, and since it is often unnecessary to know the exact amount of voltage present in the wave, much

simpler measuring devices are often used. These measure relative field strength instead of absolute field strength. Relative field strength measurement is a comparison of the strength of one radio wave with that of another or with an arbitrarily selected standard.

Relative field strength measurements are of importance when an antenna is being tuned, oriented, or modified in any way. The usual procedure in such operations is to place the relative field strength meter at a considerable distance (not less than several wavelengths) from the antenna being measured. Readings are taken before the antenna is adjusted or the equipment modified. After adjustment, the field strength readings are taken again and compared with the previous values to determine the effect of the changes on the radiated signal strength.

Most relative field strength meters are either of the crystal rectifier type or the vacuum tube voltmeter type. Each of these employs one or more tuned circuits, a pickup antenna, some type of rectifier, and a current indicator. The pickup antenna is placed in the radiated field and the tuned circuit set in resonance at the frequency of the signal to be tested. The voltage induced in the tuned circuit is rectified either by a crystal rectifier or by a vacuum tube. In the crystal type, the rectified current is usually applied directly to the current meter, and the deflection of the meter is an indication of the strength of the signal. In the vacuum tube voltmeter type of field strength meter, the voltage developed in the rectifier is applied to the grid of an amplifier. The grid voltage results in a deflection of the current meter which is placed in the plate circuit of the amplifier.

In (A) of figure 3–27 a simple type of crystal detector field strength meter is shown. The crystal detector is mounted in the center of a pickup antenna, whose length ideally is one-half wave at the frequency of the received signal. The crystal is coupled to a 0–1 milliammeter through radio-frequency choke coils. The induced signal is rectified by the crystal and the resulting current is indicated on the milliammeter. This type of meter is used at distances of

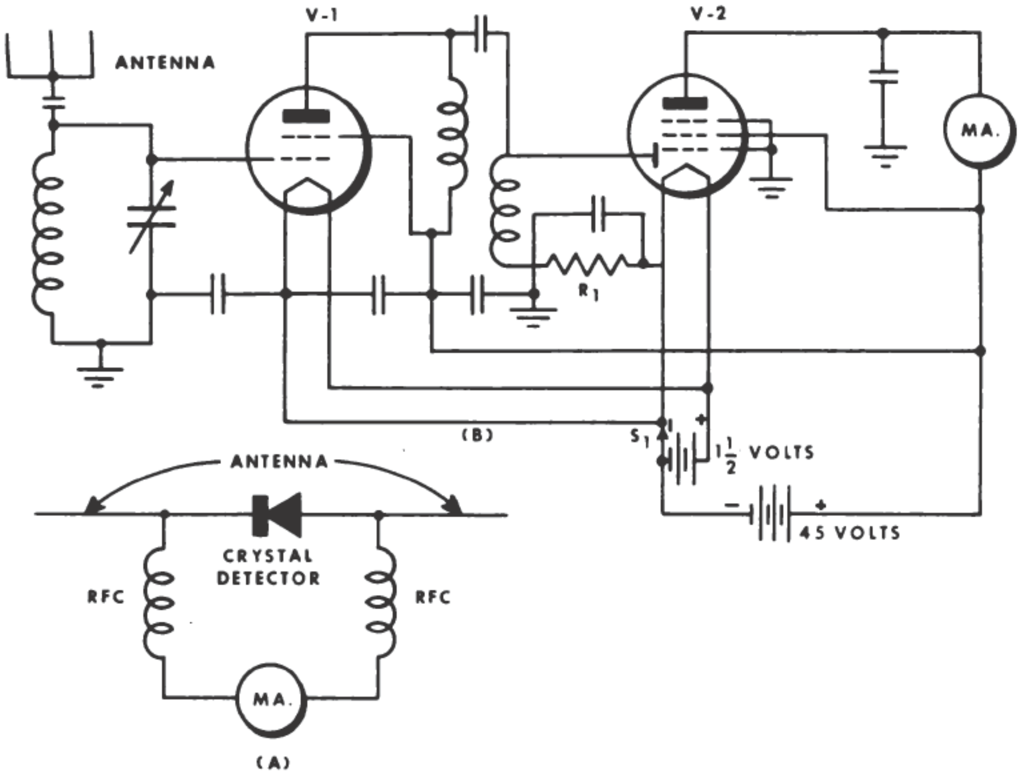


Figure 3–27.—(A) Crystal field strength meter; (B) vacuum tube field strength meter.

four or five wavelengths from the transmitting antenna and for low-power transmitter measurements.

In (B) of figure 3–27 a considerably more sensitive field strength meter is shown. The tube V1 is an r-f amplifier, the output of which is applied to the diode section of V2, a detector-amplifier. The rectified signal voltage is developed across R_1, one end of which is attached to the filament-cathode of the amplifier tube. The voltage developed across R_1 controls the plate current of V2 which is read on the milliammeter in the plate lead. The amount of change in the plate current is an indication of the strength of the signal induced in the pickup antenna of the field strength meter.

The tube V2 is a variable-mu pentode. In this type of amplifier, large signal voltages are amplified by a relatively small amount and small signal voltages receive much greater amplification. The Eg–Ip curve of such a tube is essentially

a logarithmic curve. As a result of this fact, the meter in vacuum tube field strength circuits of this type can be calibrated directly in decibels, a logarithmic unit of power or voltage level.

When using field strength meters, errors and erratic readings can be caused by the presence of objects or persons near either the radiating source or the test meter, resulting in shadows and reflections in the radiated field.

The antenna of the test meter should always be extended to its full length so as to keep its effect on the tuning circuit constant.

Many types of field strength indicators are intended for use within 25 feet of the equipment being tested when antenna adjustments are made to achieve maximum radiation. The distance which results in the most satisfactory operation of the instrument for this test varies with the type of equipment being tested. Usually it is desirable to select a distance for the measurements which give a meter reading at about half-scale.

CRYSTAL RECTIFIER TESTING

The function of a crystal rectifier test set is to provide a quick and accurate means of testing a crystal rectifier in the field. Although the complete testing of a crystal rectifier is an elaborate procedure requiring precision radio-frequency test equipment, the test sets usually provided are sufficient for determining whether or not the crystal rectifier is satisfactory for use. Crystal testing is accomplished by measurement of the forward and backward resistance, and usually the back current at 1.0 volt.

A crystal rectifier is a device used for converting r-f energy into unidirectional current. It usually consists of a small piece of silicon in contact with a thin tungsten wire (called a cat whisker), both of which are mounted in a small cartridge-type container. The rectification takes place at the contact between crystal and cat whisker, and is due to the fact that the resistance in one direction is greater than that in the other direction as in a vacuum tube used as a rectifier or detector. The properties of the rectifier depend critically

on the type of contact area, and the place of contact. The crystal rectifier has been carefully adjusted at the factory, and should not be upset by tampering with the setscrew.

A crystal rectifier is illustrated in figure 3–28. The crystal is designed so that current normally flows from the tip to the base (tungsten to silicon). The area of contact within the crystal rectifier housing is very small, and if too much current is passed through the cartridge, the resulting heat will damage it, causing the operation of the crystal rectifier to be impaired or the unit to burn out completely.

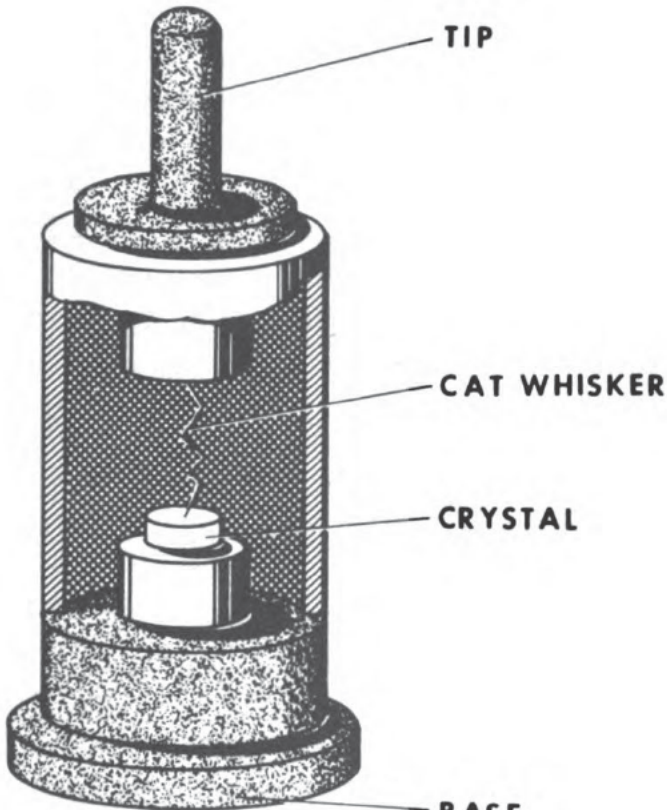


Figure 3–28.—Crystal rectifier.

Crystal rectifiers may be damaged by static discharges. The operator should be sure that any static charge which may be present on the body is discharged by momentarily touching (grounding) a finger or the hand to the ground contact of the test set or equipment in which the crystal is to be installed.

Because of the possibility of damage due to strong r-f fields which may be present, crystal rectifiers are stowed in metal containers or in metal foil except when they are being tested or used.

The circuit diagrams of a typical crystal rectifier test set are illustrated in figures 3–29 and 3–30. The figures show two arrangements of the same device. The test set can be changed from the resistance measuring arrangement to the back-current circuit by the action of a selector switch. The meter shown in the two figures is calibrated for both resistance and current measurements. It contains a 0–1 milliampere movement with an internal resistance of approximately 100 ohms.

The circuit shown in figure 3–29 is used for forward and backward resistance determination and is similar to the circuit of a simple ohmmeter. With switch S1 set to the ZERO ADJUST position, the milliammeter is first set for maximum (1.0 ma.) current, or zero indicated resistance, by adjustment of the series potentiometer R102. The forward and backward resistance can then be measured by rotating S1 to the appropriate position and placing the crystal rectifier in the proper holder. If no further change has been made in the position of the control R102, the additional resistance which the crystal rectifier introduces into the circuit causes a de-

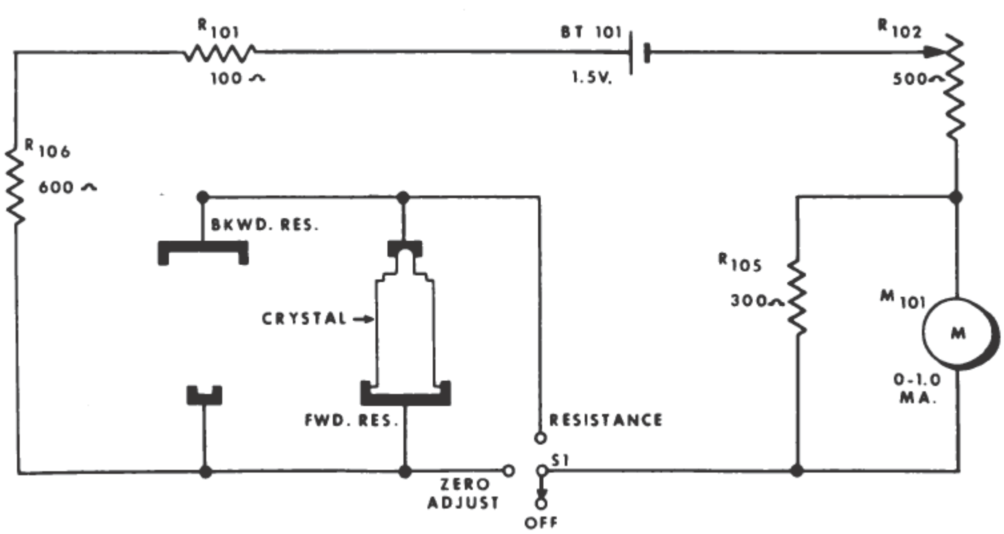


Figure 3–29.—Rectifier test set schematic—resistance measurement.

crease in the current flow, and the meter will then deflect to some point on the scale other than full deflection.

The forward, or "front," resistance of the crystal is the resistance measured with normal current flowing (comparable to the cathode-to-plate current flow in a diode vacuum tube). The crystal rectifier is considered unfit for use if this resistance is greater than 500 ohms.

The backward, or "back," resistance of the crystal is a measure of resistance to current flow from the crystal to the whisker in the rectifier. This current flows from the rectifier base to the tip and is comparable to any current flowing from the plate to the cathode in a diode vacuum tube. The crystal rectifier should be rejected for use if the ratio of back resistance to front resistance is less than 10 to 1.

For example, if the meter reading is 400 ohms when the forward resistance is measured, then the back resistance must be at least 4,000 ohms or more if the crystal is considered to be usable.

In addition to the circuit arrangement for checking the resistance ratio of the crystal rectifier, many test sets are provided with means for measuring the back current through the rectifier with an applied voltage of 1.0 volt. This is a more accurate measure of the condition of the crystal than the resistance-ratio check. The circuit arrangements for this check are illustrated in figure 3–30. In (A) of the figure, the circuit is shown in the condition used for the initial voltage adjustment.

Before the back current is measured, the meter must be adjusted so that an effective voltage of 1.0 volt is impressed across points 1 and 2. Since the back resistance of a crystal rectifier is a high value, the effective resistance of the parallel circuit between points 1 and 2 in (A) of the figure is essentially that of the meter and R103, or 1,000 ohms. The full-scale reading of the milliammeter is 1.0 milliampere; therefore, an adjustment of R102 resulting in full-scale deflection of the meter insures a voltage of 1.0 volt across the parallel circuit.

After the voltage has been adjusted, the circuit is switched

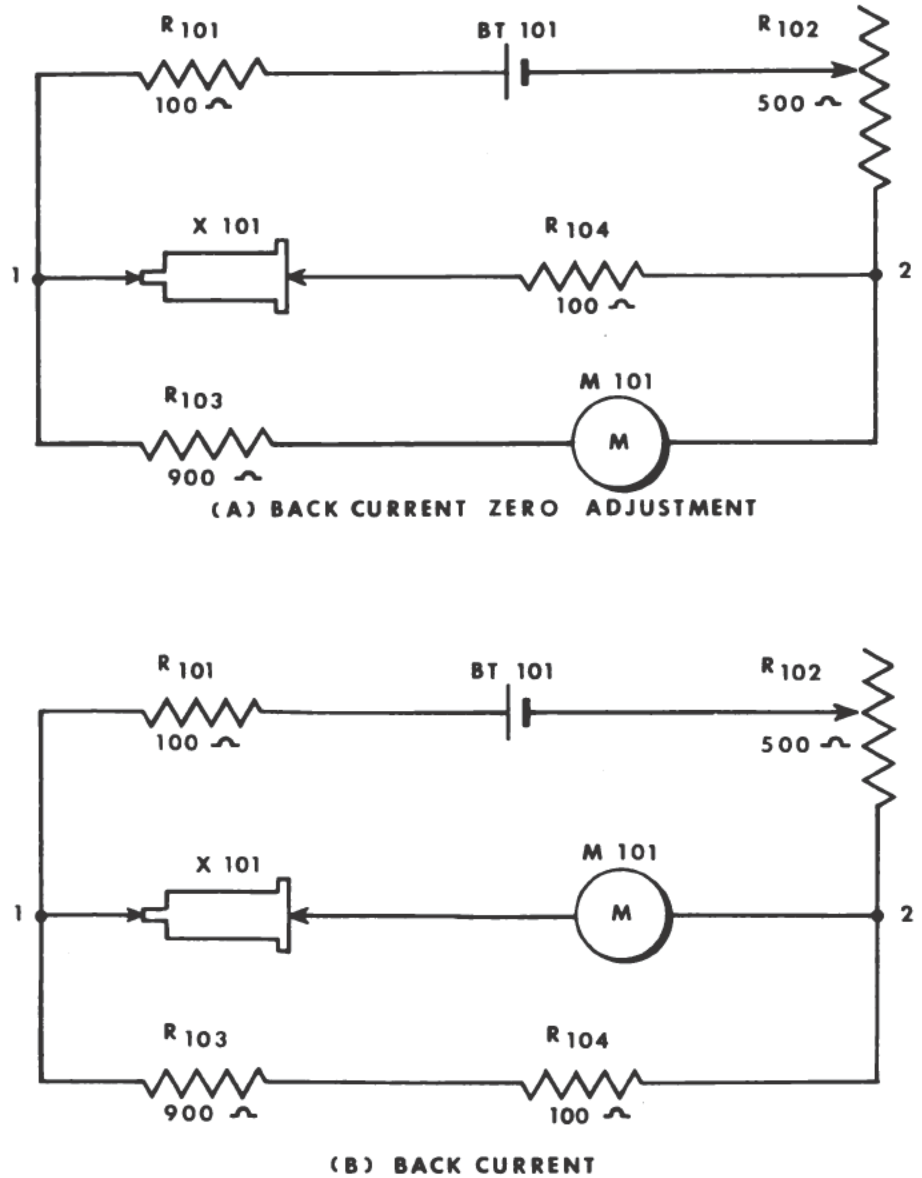


Figure 3–30.—Rectifier test set schematic—back current measurement.

to the condition shown in (B) of figure 3–30 to measure the back current. In this condition, the positions of the crystal rectifier and R103 are exchanged so that the crystal is now in series with the milliammeter which has negligible resistance compared with that of the rectifier. With 1.0 volt impressed across this circuit, the meter then indicates the current flowing through the crystal rectifier. The magnitude of this current is inversely proportional to the backward resistance of the crystal. The scale of the meter is usually marked to

indicate the maximum limits of back current for the crystal rectifiers in common use.

The maximum allowable back current varies somewhat with temperature. The lower the temperature, the lower the maximum limit of back current. Temperature correction tables are included with the instruction manuals of most test sets. These should be consulted when the surrounding temperature is considerably lower or higher than 70 degrees F. (approximately 22 degrees C.).

WAVEMETERS

Wavemeters are calibrated resonant circuits used to measure frequency. Although the accuracy of wavemeters is not as high as that of heterodyne frequency meters, they have the advantage of being comparatively simple and can be easily carried about.

Any type of resonant circuit may be used in wavemeter applications. The exact kind of circuit employed depends on the frequency range for which the meter is intended. Resonant circuits consisting of coils and capacitors are used for low-frequency wavemeters. Butterfly circuits, adjustable transmission line sections, and resonant cavities are used in VHF and microwave instruments.

There are three basic kinds of wavemeters: The absorption, the reaction, and the transmission types. Absorption wavemeters are composed of the basic resonant circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type of wavemeter is loosely coupled to the circuit to be measured. The resonant circuit of the wavemeter is then adjusted until the current meter shows a maximum deflection. The frequency of the circuit under test is then determined from the calibrated dial of the wavemeter.

The reaction type derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit being measured. For example, the wavemeter is loosely coupled to the grid circuit of an oscillator and the resonant circuit of the meter is adjusted until it is in resonance with the oscillator frequency. The setting of the wavemeter dial

is made by observing the grid-current meter in the oscillator. At resonance, the wavemeter circuit takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the calibrated dial of the wavemeter.

The transmission wavemeter is an adjustable coupling link. When it is inserted between a source of radio-frequency energy and an indicator, energy is transmitted to the indicator only when the wavemeter is tuned to the frequency of the source. Transmission wavemeters are widely used in measuring microwave frequencies.

In figure 3–31 a typical cavity wavemeter is illustrated.

The wavemeter illustrated is of the type commonly used for the measurement of microwave frequencies. The device employs a resonant cavity which effectively acts as a high-Q LC tank circuit. The resonant frequency of the cavity is varied by means of a plunger which is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity reduces the cavity-size and increases the resonant frequency. Conversely, an increase in the size of the cavity (made by withdrawing the plunger) lowers the resonant frequency. The microwave energy from the equipment under test is fed into the wavemeter through ons of two inputs, (A) or (D). A crystal rectifier then detecte, or rectifies, the signal and the rectified current is indicated on the current meter, M.

The instrument can be used as either a transmission type or an absorption type wavemeter. When used as a transmission wavemeter, the unknown signal is coupled into the circuit by means of input (A). When the cavity is tuned to the resonant frequency of the signal, energy is coupled through coupling loop (B) into the cavity and out through loop (C) to the crystal rectifier where it is rectified and is indicated on the meter. At frequencies off resonance little or no current flows in the detector and the meter reading is small. Therefore, the micrometer and attached plunger are varied until a maximum meter reading is obtained. The micrometer setting is then compared with a calibration chart

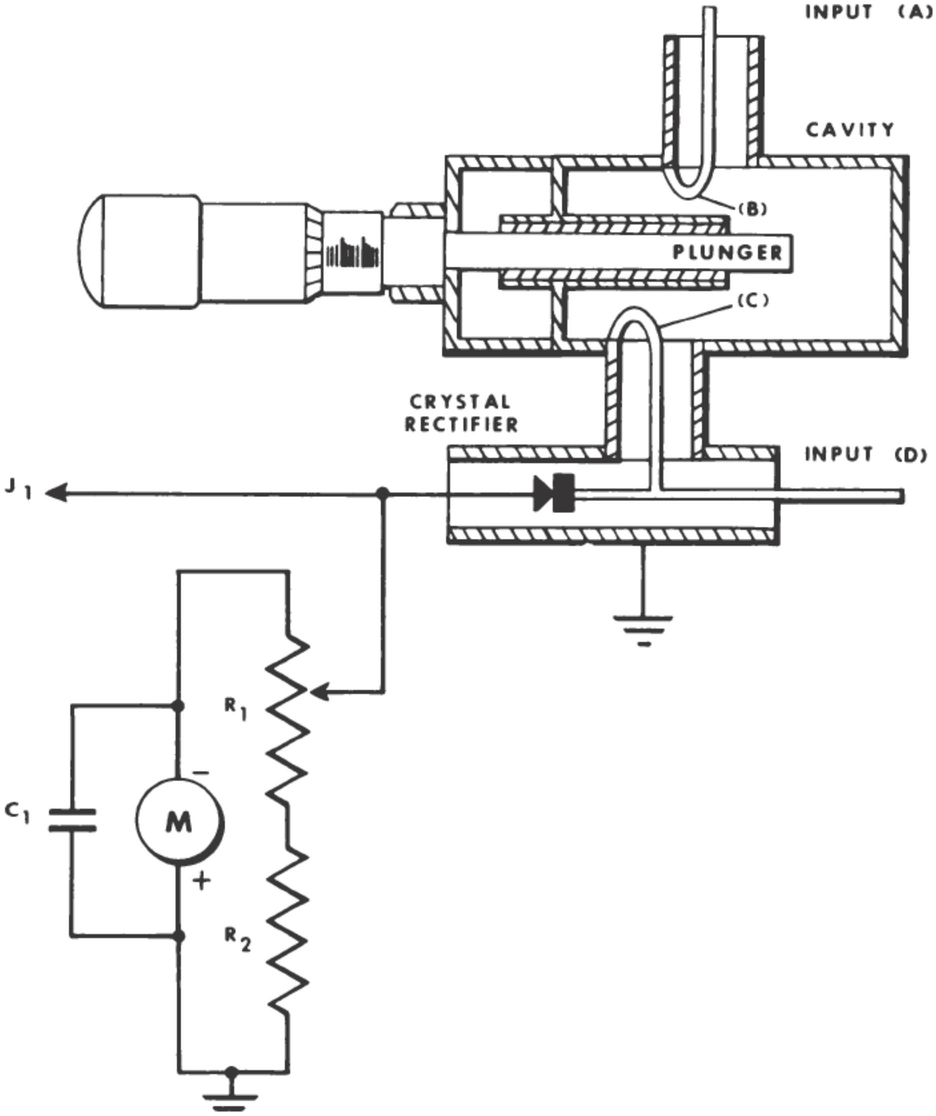


Figure 3-31.—Typical cavity wavemeter.

supplied with the wavemeter to determine the unknown frequency.

When the unknown signal is relatively weak, such as the signal from a klystron oscillator, the wavemeter is usually used as an absorption type of device. Connection is made to the instrument at the input (D). The r-f loop (C) then acts as an injection loop to the cavity. When the cavity is tuned to the resonant frequency of the klystron, maximum energy is absorbed by the cavity and the current indicated on the meter dips. When the cavity is not tuned to the frequency of the klystron, high current is indicated on the current

meter. Therefore, the cavity is tuned for a minimum reading, or dip, in the meter, and the resonant frequency is determined from the micrometer setting and the calibration chart.

The potentiometer, R_1, is used to adjust the sensitivity of the meter from the front panel of the instrument. J_1 is a video jack and is provided for observing video waveforms with a test oscilloscope.

A directive antenna is used in conjunction with the instrument for making relative field strength measurements of radiated signals, for use in measuring the frequency of radar transmitters, and for constructing radiation patterns of transmitting antennas.

In radiation pattern measurements, the directive antenna is connected to the wavemeter input and the instrument is tuned to the frequency of the system under test. The cavity is then locked on this frequency. The output signal being measured must be continuous and constant for reliable results. This is necessary in order for any variation in the meter reading to be caused directly by a change in the actual field strength of the signal when the position of the wavemeter is changed with respect to the transmitting antenna. After establishing a reference level on the meter, the position of the wavemeter is then changed by moving it around the radiating antenna, maintaining a fixed distance from it. The wavemeter readings at various positions around the transmitting equipment are recorded on polar graph paper and the field pattern thereby determined.

QUIZ

1. The purpose of the electron gun is to
   a. deflect the electron stream
   b. collect secondary electrons
   c. produce and focus electrons
   d. produce a sweep voltage

2. Electrons flow from the cathode to the screen of an electrostatic cathode-ray tube in which of the following sequences?
   a. Cathode, control grid, focusing anode, accelerating anode, deflection plates, screen
   b. Cathode, accelerating anode, focusing anode, screen
   c. Cathode, control grid, deflection plates, accelerating anode, focusing anode, screen
   d. Cathode, control grid, focusing anode, deflection plates, accelerating anode, screen

3. In an electrostatic cathode-ray tube the movement of the spot traced on the face of the tube by the electron beam is controlled by the
   a. voltages applied to the focusing anode
   b. signal applied to the control grid
   c. aquadag coating
   d. voltages applied to the deflection plates

4. In a cathode-ray tube secondary emission electrons are collected by the
   a. screen grid
   b. suppressor grid
   c. aquadag coating
   d. deflection plates

5. Intensity control in the cathode-ray tube is usually obtained by varying the voltage
   a. between the cathode and control grid
   b. on the deflection plates
   c. between the cathode and the deflection plates
   d. between the filament and cathode

6. In an electrostatic cathode-ray tube focusing is accomplished by adjusting the potential difference between the
   a. cathode and control grid
   b. control grid and first anode
   c. first anode and second anode
   d. second anode and deflection plates

7. The potential at which the gas ionizes and conduction begins in a gas-filled tube is called the
   a. firing potential
   b. de-ionizing potential
   c. plate potential
   d. B plus

8. The output of the sawtooth generator in an oscilloscope is applied to the
   a. control grid
   b. focusing anode
   c. deflection plates
   d. cathode

9. In order to observe three cycles of a waveform, the sweep frequency of a cathode-ray tube should be
   a. twice the signal frequency
   b. half the signal frequency
   c. one-third the signal frequency
   d. equal to the signal frequency

10. The purpose of using shielded test leads in oscilloscope operation is to
    a. prevent radiation
    b. minimize pickup of stray fields
    c. protect the operator
    d. provide a good ground

11. From the list below, the most acceptable standard for PRECISE adjustment of the oscillator in a frequency meter is
    a. another frequency meter
    b. a crystal-controlled oscillator
    c. a calibrated transmitter (ART–13)
    d. WWV

12. Calibrating the output of a signal generator is necessary in order to
    a. know the amplitude of the output signal
    b. know the amount of modulation present on the output signal
    c. know the approximate output frequency
    d. match the impedance of the generator to the device being tested

13. The device used for exhibiting the spectrum of modulated waves is known as which of the following?
    a. Spectrum meter
    b. Spectrum graph
    c. Spectrum analyzer
    d. Echo box

14. Unwanted effects such as frequency modulation in a pulse radar system can be detected by the use of a
    a. spectrum analyzer
    b. signal generator
    c. wavemeter
    d. frequency meter

15. Power absorption cones are primarily used to
    a. provide an absorbing shield in order to prevent radiation
    b. absorb the target return
    c. prevent the returned echo from entering the receiver
    d. allow the transmitted signal to return without loss of power

16. A device used to supply a standard reference signal to a radar system under test is the
    a. oscilloscope
    b. spectrum analyzer
    c. wavemeter
    d. echo box

17. NORMAL return signals should not be used as a standard in radar adjustments because they
    a. may vary in accordance with atmospheric condition
    b. never vary which is undesirable
    c. always vary which is desirable
    d. have a tendency to drift

18. Echo boxes can be used to
    a. measure relative power and to check the frequency of the transmitter and local oscillator
    b. generate r-f signals
    c. check for frequency only
    d. measure peak power

19. Basically an echo box is a
    a. superheterodyne receiver
    b. resonant cavity with a very high Q
    c. resonant cavity with a very low Q
    d. resonant cavity

20. The time between the end of the transmitted pulse and the time when the return energy from the echo box falls below the minimum required to give a radar indication is known as
    a. pulse width
    b. bandwidth
    c. ringing time
    d. pulse time

21. The device used to plot an antenna radiation pattern is the
    a. echo box
    b. field strength meter
    c. frequency meter
    d. spectrum analyzer

22. A crystal being checked in the crystal rectifier test instrument should be rejected when the back-to-front resistance is
    a. less than 10:1
    b. more than 10:1
    c. less than 20:1
    d. more than 20:1

23. A crystal under check in the crystal rectifier tester should be rejected when the front resistance is greater than
    a. 200 ohms
    b. 300 ohms
    c. 400 ohms
    d. 500 ohms

24. When using the REACTION TYPE wavemeter, the frequency of an oscillator being measured is indicated by a/an
    a. dip in grid current of the oscillator
    b. increase in grid current of the oscillator
    c. zero change in grid current of the oscillator
    d. increase in plate current of the oscillator

CHAPTER 4

AIRCRAFT ELECTRONIC MAINTENANCE

LOCALIZING DEFECTIVE PARTS

The materials used in Navy electronic equipment are considered to be the best obtainable for the purpose involved. The equipment has been carefully inspected and adjusted at the factory in order to reduce maintenance to a minimum. However, a certain amount of checking and servicing will always be necessary if electronic equipment is to be kept in efficient and dependable operation. The electronic technician is concerned with such checking and servicing. A large part of his activity is devoted to preventing electronic failure by detecting defective operation and component deterioration in the early stages. This is accomplished by routine inspections of the equipment. These inspections are usually of several kinds: Preflight inspection, daily inspection, 100-hour inspection, and the checks made during the periodic inspections of the aircraft.

When defective parts or unsatisfactory operation have been revealed in any of the inspections, it is necessary to analyze the equipment, find the defective part or parts, and make the appropriate replacement or repair. In general, the most effective procedure for this analysis consists of first isolating the stage containing the defect and then locating the particular part at fault by careful measurements within the stage.

The general methods which are used in locating defective electronic stages and parts can be listed as follows:

1. Preliminary visual and operating checks.
2. Voltage measurements.
3. Resistance measurements.
4. Current measurements.
5. Signal tracing methods.

Preliminary Visual and Operating Checks

A visual (and audible) check, together with a check on the operation of the equipment, provides a logical first step in arriving at a defective part. In this stage of servicing, the equipment is inspected for broken leads, parts which are burned or smoking, controls which are not functioning normally, resistors which smell hot or which feel abnormally hot to the touch, tubes which are dark when the equipment is turned on, loose fastenings, and any other indications of failure.

In servicing electronic equipment such as transmitters, the initial operating check is made by observing the front-panel meters which, in the special case of transmitters, make it possible to determine quickly whether grid current, plate current, and antenna current are present.

In the preliminary check, the experience of the technician is an important factor, and the knowledge gained from previous difficulties with the device often serves as a guide in knowing what to expect. Both the experienced and the inexperienced can find assistance in preliminary checking by consulting the instruction manuals for the specific equipment involved, since these often give detailed procedure for making the initial inspections. However, many electronic faults do not result in symptoms which can be detected visibly or audibly, and it is frequently necessary to resort to other methods of detecting part failure.

Voltage Measurements

Voltage measurements, which are often used to find defective parts, are made at various points in the stage suspected

of being at fault. The observed voltage values are then compared with the normal voltage values given in the *Handbook of Service Instructions*, and from this comparison, the defect can often be isolated. Voltage checks are most effective when applied within a single stage, and after previous checks have been made to partially localize the defect. This is true because modern electronic equipment is complex, and a great deal of time is required to check all the voltages present in all the stages.

Resistance Measurements

This method is similar to voltage checking except that the equipment is switched off and resistance values are measured with an ohmmeter. The resistance values are then compared with the normal values given in the maintenance publications. This method, like voltage measurement, is most effectively used after the trouble has been isolated to a particular stage since reliance on resistance measurement alone is too time-consuming to be efficient. After the trouble has been isolated, the ohmmeter is a very useful instrument and often leads the technician quickly to the trouble.

A typical example of a routine resistance check applied to a single part is the ohmmeter method of checking electrolytic capacitors. A resistance measurement is made on the discharged capacitors, using the high-resistance range of the ohmmeter. When the ohmmeter leads are first applied across the capacitor, the meter pointer rises quickly and then drops back to indicate a high resistance. The test leads are then reversed and reapplied. The meter pointer should rise again—even higher than before—and again drop to a high value of resistance. The deflections of the meter are caused when the capacitor is charged by the battery of the ohmmeter. When the leads are reversed, the voltage in the capacitor adds to the applied voltage, resulting in a greater deflection than at first.

If the capacitor is open-circuited, no deflection will be noted. If the capacitor is short-circuited, the ohmmeter

indicates zero ohms. The resistance values registered in the normal electrolytic capacitor result from the fact that there is leakage present between the electrodes. A fairly typical set of values is 50,000 ohms in one connection and 500,000 ohms in the reversed polarity of the meter. The difference in resistance results because the capacitor is a polarized device.

Current Measurements

Current measurements can be made in various circuits of the equipment to detect the presence of abnormal values. After the circuits have been measured, the readings are compared with the normal values given in the maintenance notes.

In troubleshooting the radio-frequency sections of transmitters and other equipment in which front-panel current meters are usually included, current measurement is a valuable first step in finding trouble. But in receivers and many other types of devices, these measurements can be made only after the circuits have been opened and the meter inserted in series with the part in question. When the meters are not present, this is a time-consuming process and, as a result, voltage or resistance checks are preferred in such cases.

Signal Tracing

Signal tracing is a very effective method for locating defective stages in many types of electronic equipment. It is especially useful when servicing radio receivers, audio amplifiers, and other equipment which normally contain no built-in meters. In signal tracing, a signal voltage similar to that which is present in the operation of the stage is taken from a signal generator and is then applied to the input terminals of the circuit in question. The signals which result from this application are then checked at various points in the device, using test instruments such as vacuum tube voltmeters, oscilloscopes, output meters, or any high impedance instrument which is appropriate. (The test instrument should have high impedance so that it will not change the operation of the circuit to which it is applied.)

By signal tracing methods, the gain or loss of amplifiers can be measured; and the points of origin of distortion and hum, noise, oscillation, or any abnormal effect can be localized.

The gain measurement can be used as an example of an important method in signal tracing. By this procedure, a defective stage can be found quickly in a radio receiver or audio amplifier. A signal generator with the output attenuator calibrated in microvolts and an output meter are used. It is helpful to have data concerning the normal gain of the various stages of the device. These data are generally found in the *Handbook of Service Instructions* for the receiver under test.

The output meter is connected across the voice coil of the receiver or across the primary of the output transformer. The output of the signal generator is applied to the grid circuit, or input terminals, of one of the amplifiers. The attenuator of the signal generator is then adjusted until the output meter reads an appropriate value which will serve as a reference figure. The output of the signal generator is then applied to the output of the stage under test (or to the grid of the next stage), and the attenuator is adjusted until the reference value again is registered on the output meter. The gain of the stage is found by dividing the second value of the signal (taken from the calibrated attenuator) by the value of the signal applied to the input of the stage.

As an example, suppose the signal generator delivers a voltage of 400 microvolts to the grid of an i-f amplifier to cause the output meter to indicate the reference value. When the generator signal is applied to the following grid, the signal strength must be increased to 4,000 microvolts to cause the output meter to indicate the reference value. The gain of the stage is $\frac{4{,}000}{400}$ or 10.

If similar measurements made in the remaining stages of the receiver reveal one in which the gain is lower than normal or is zero, that stage can then be thoroughly checked by voltage measurement, by resistance measurement, or by simple replacement of parts until the defective one is found.

When making stage gain measurements in receivers, the

value of the applied signals must be low enough to prevent the AVC system from functioning; otherwise, the measurements will not be accurate. In *Handbooks of Service Instructions*, the recommended signal values are usually stated in terms of the reference value to be used at the output meter. For example, the generator signal recommended for this measurement in the AN/ARC–5 receivers is that voltage which produced 10 milliwatts in the output of the receiver. (This is equal to 1.73 volts applied to a 300-ohm resistive load.)

One of the most frequent sources of trouble in electronic equipment is failure of vacuum tubes. It would seem from this that the first step in electronic maintenance should be the testing of all such tubes in a tube tester. While tube testers fill a useful and necessary place in electronic maintenance, it should be remembered that these instruments have certain limitations. The leading objection is that testers do not necessarily test the tube under operating conditions.

Tube testers are of two general types: emission testers and mutual conductance testers. In the emission tester, the filament and cathode of the tube are heated, and fixed voltages are applied to the tube electrodes. The resulting tube current is then measured to determine the amount of emission present. The test is based on the fact that as a tube ages, the amount of emission from the cathode usually decreases.

In the mutual conductance tester, the changes in plate current resulting from small changes in grid voltage are measured. This type of test comes nearer the ideal of testing the tube under operating conditions; however, in the mutual conductance tester as well as in the emission tester, it frequently happens that the tube condition is indicated as good when the performance of the tube under actual working conditions is poor.

A better check of a doubtful receiving tube is to test it in the equipment by applying a signal from a signal generator to the questionable stage and noting the output of the receiver on an output meter. Substitution of a tube known to be good is then made and the resulting output is compared with the former value.

The methods discussed above are very general and apply to the maintenance of almost any type of electronic equipment. To illustrate application of these methods to a particular case, the following sections contain a summary of the authorized maintenance procedure for the AN/ARR–15 radio set.

Preliminary Visual and Operational Checks

The AN/ARR–15 radio set to which the following procedure applies consists of a receiver and a dynamotor power supply. Additional equipment includes an antenna and a 26.5-volt, d-c power source. The receiver is equipped with an autotune method of frequency control. This system is an electrically controlled means of setting variable capacitors and inductors in the tuning circuits. Any one of ten channels is available, and any one of these may be selected by operating a switch on the receiver panel.

To assist in following the procedure, the block diagram of the receiver is shown in figure 4–1. (The stage labelled "Exciter" consists of an oscillator and a frequency multiplier.)

A large part of the preliminary checking is made in the form of regularly scheduled inspections. The first of these is the preflight inspection.

Preflight inspection procedure.—This inspection is made to insure proper functioning of all parts and to be sure that the units are securely fastened.

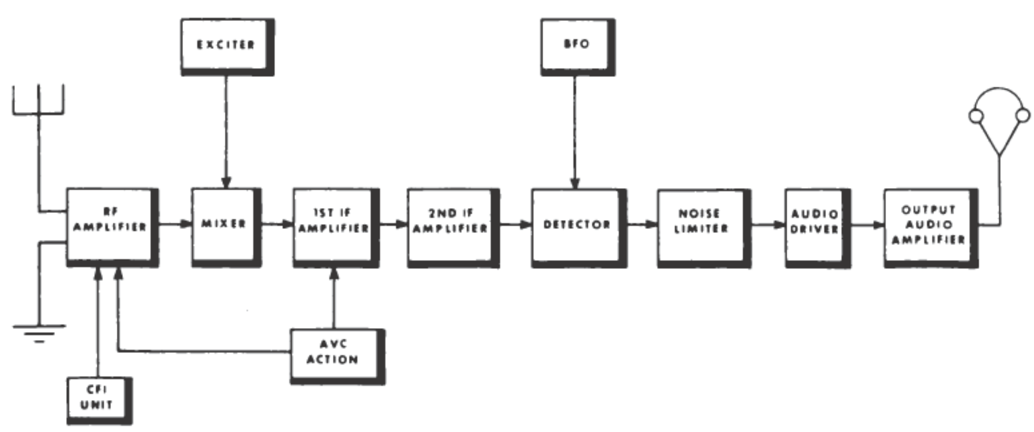


Figure 4–1.—Block diagram of the AN/ARR–15 radio receiver.

The visual check in the preflight inspection consists of the following steps:

1. The autotune locks on the band switch and the tuning control are inspected to be sure that both are tight.
2. The antenna and the antenna terminal connection are checked for tightness.
3. The mounting base, the securing clamps, the remote control unit, and all interconnecting cables are checked for tightness.
4. Any loose or broken wires are noted.
5. The headphones are checked for loose or broken wires.
6. The receiver is turned on and checked for normal operation.

DAILY CHECK.—This inspection is designed to determine, in general, the condition of the complete equipment and to detect and correct any aggravated conditions, maladjustments, broken wires, or defective components. The visual inspection is similar to that of the preflight check.

In the operational check, the receiver is tested for sensitivity against stations of known signal strength on all channels. The controls of the remote control unit are tested for proper operation. The dynamotor is inspected to see if it is running smoothly.

THE 100-HOUR INSPECTION.—This inspection involves the removal of the chassis followed by a searching visual and operational inspection. This inspection is made to detect maladjustments and early stages of parts deterioration. The amount of servicing required is also determined.

The visual inspection consists of the following steps:

1. The receiver is removed from the mounting base.
2. The dynamotor is removed from the chassis, the end shields are removed, and the commutator and brushes are checked for wear.
3. The receiver vacuum tubes are checked to see that all are tight in their sockets.
4. All moving parts in the receiver and associated parts that may have become loose due to vibration are inspected.

5. All capacitors, resistors, and other parts are checked for evidences of deterioration and corrosion.
6. The relay contacts and switch contacts are checked for corrosion and pits.

The operational check is conducted as follows:

1. The receiver unit and dynamotor unit are installed and the power cables are connected to the 26.5-volt supply.
2. The phones are plugged in and a ground lead is connected to the receiver mounting base.
3. Each of the ten channels is selected on the dial and the autotune cycle is noted for each.
4. A signal generator is connected to the antenna terminal of the receiver through a dummy antenna that consists of 10 ohms of noninductive resistance and 100 micro-microfarads of capacitance in series.
5. An output meter is connected to the receiver output, and the control switch turned to the ON position. The sensitivity of the receiver is checked against the table of sensitivity values given in the *Handbook of Service Instructions*. All ten channels and all six bands are checked in this way.
6. A list of suggested preliminary checks for the troubles which may be found during the inspection procedure follows:

Symptom	*Possible Source of Trouble*
Equipment dead	1. Defective switch. 2. Defective primary power control relay. 3. Broken connection in primary power circuit.
Autotune operative but dynamotor does not run.	1. Defective motor brushes. 2. Dynamotor windings open. 3. Open circuits in wiring.
Receiver operative but will not change channels.	1. Defective relay. 2. Defective channel selector switch. 3. Autotune brushes not making proper contact. 4. Autotune motor winding open.

Symptom—Con.	*Possible Source of Trouble*—Con.
No signals received	1. Defective tubes. 2. Defective relay. 3. No plate voltage. 4. Defective circuit connections.
Receiver noisy	1. Defective tube. 2. Loose wiring. 3. Open filter or bypass capacitor. 4. Defective relay contacts.
Oscillation in receiver	1. Open bypass capacitor. 2. Defective ground connection. 3. Defective tube. 4. Defective shielding.
Signals weak	1. Weak tubes. 2. Low voltages. 3. Improper tuning. 4. Misalinement of circuits.

In following the suggestions given in item 6, voltage measurements, resistance measurements, and tube substitution are used. If the trouble cannot be located from this procedure, it is then necessary to make a stage-by-stage check.

Stage-by-Stage Location of Trouble

The test equipment required is an audio signal generator, a radio-frequency signal generator, and a capacitor of about 0.01 microfarad in value.

The AN/ARR–15 receiver, illustrated in the block diagram in figure 4–1, is again selected as an example. The audio amplifier stages are checked first.

Audio stages.—The following procedure is used in testing the operation of the audio amplifiers:

1. Connect the output of an audio signal generator through a 0.01 microfarad capacitor to the plate of the second audio amplifier tube. (Refer to fig. 4–1.) Connect the generator ground lead to the chassis of the receiver.
2. Adjust the output of the audio signal source to approximately 1,000 cycles per second; adjust the receiver volume control to the maximum setting.

3. Turn on the audio generator and the receiver and allow ample time for all tubes to reach normal operating temperature.
4. The 1,000-cycle tone should be heard in the headphones if the output circuit of the receiver is operative.
5. Connect the audio signal to the following points in the order stated:
   a. The grid of the second audio tube.
   b. The plate of the audio driver tube.
   c. The grid of the audio driver tube.
   d. The cathode and plate of the noise limiter tube.

If any one of the audio stages is defective, the trouble will be found between the point where no signal is heard and the point at which it last was heard.

DETECTOR, AMPLIFIER, AND NOISE LIMITER CIRCUITS.—If the test signal is heard in the headphones when the output of the generator is fed to the cathode and plate of the noise limiter tube, the audio stages are operating normally and the trouble must be in a stage preceding this point.

Using a radio-frequency signal generator instead of the audio generator, connect the output lead through a 0.01 mfd. capacitor to the intermediate-frequency coil side of the detector. Connect the ground lead of the generator to the receiver chassis.

Adjust the frequency of the signal generator output to the intermediate frequency of the receiver and turn on the equipment. If a signal is heard in the phones, the circuits are operating correctly.

I-F AMPLIFIER STAGES.—Using the same procedure as in the two preceding paragraphs, apply the output from the generator to the following points:

1. The plate of the second i-f amplifier tube.
2. The grid of the second i-f amplifier tube.
3. The plate of the first i-f amplifier tube.
4. The grid of the first i-f amplifier tube.
5. The plate of the mixer tube.
6. The grid of the mixer tube.

EXCITER OSCILLATOR AND MULTIPLIER STAGE.—If the signal is heard through the i-f amplifier stages, the oscillator

and mixer stages may be checked by leaving the signal generator connected to the mixer grid, adjusting the output to a frequency within the tuning range of the receiver, and setting the receiver dial to the generator frequency. The signal will be heard if the exciter stages are operating correctly.

Radio-frequency amplifier stage.—If a signal is heard when the stages referred to in the preceding paragraph are checked, the r-f amplifier may be tested by the same receiver and signal generator settings. The procedure is as follows:

1. Connect the output of the signal generator to the plate of the r-f amplifier, and check for an output signal from the headphones.
2. Connect the signal to the grid of the r-f amplifier tube.
3. Connect the signal to the antenna connection on the receiver front panel.

Locating Trouble in an Inoperative Stage

When a fault is known to exist in a certain stage, the following procedure is used to find the defective part:

1. Replace the tube with one of the same type that is known to be in good condition, and check to see if the trouble is corrected.

2. Measure the voltage at the tube sockets. Incorrect voltage readings indicate defective wiring or components.

3. Check the capacitors for an open or short condition. A shorted capacitor usually causes improper voltage values in the stage and may cause resistors and other components to heat excessively. An open capacitor may be located by shunting the suspected unit with a test capacitor of its same value. An open capacitor causes noise, oscillation, or absence of signal.

4. With the receiver turned off, measure the values of the fixed and variable resistors in the circuit.

5. With an ohmmeter and a schematic diagram of the circuit, check the continuity of the wiring, coils, transformers, relay contacts, and relay coils.

6. Replace any parts found defective in the above checks

and operate the receiver to determine if the trouble has been completely eliminated.

REPLACEMENT OF PARTS

The *Illustrated Parts Breakdown* handbook issued with each major electronic unit provides detailed information on all parts used in the unit. In the Introduction, there is a section labeled "Ordering Spare Parts" which reads as follows:

"Each Service using this *Illustrated Parts Breakdown* has established certain depots and service groups for the storage and issuance of required spare parts to its organizations. The regulations of each Service should be studied to determine the method and source for requisitioning spare parts. The information given in this breakdown regarding a contractor's or manufacturer's name, or the type, model, part, or drawing number of any part, is not to be interpreted as authorization to field agencies to attempt to purchase identical or comparable spare parts directly from the manufacturer, or from a wholesale or retail store, except under emergency conditions, as covered by existing regulations of the Service concerned. . . .

"If a JAN or AN standard part number is given to a part, only a JAN or AN standard part should be used as a replacement. If no JAN or AN standard part number is given, care should be taken in the choice of a replacement part other than that listed. . . . Parts not assigned a JAN or AN standard part number are special parts, probably chosen for a quality not available in standard parts, and the use of standard parts for replacement purposes may result in decreased equipment life or substandard performance."

In view of this requirement for exactness in parts replacement, it is necessary that the technician know the sources of information concerning the selection of parts. To illustrate the data available, consider the following example of the entries in the component parts list:

R–713; R16–R–17311–165; RESISTOR, fixed: composition; 24,000 ohms$\pm$5%; 2w.

RC 40BF243J

JAN Designation

The first entry, R–713, is the reference symbol number

which serves to identify the part with respect to the schematic diagram of the equipment.

The second letter-number combination is the stock number of the part. Following the stock number is the part description. The description states the type of construction; the value of the component in the appropriate unit, such as ohms for resistors; the tolerance, or possible variation from the rated value; and in the case of resistors, the wattage rating. (In addition to the description, some handbooks also give the function of the component in the equipment.)

Associated with each part listed is an entry called the "Source Code." These symbols give information concerning (1) the source of supply, that is, whether the part is to be procured from supply sources, manufactured by the using activity, manufactured by an O & R Department, or obtained from salvage; (2) the level at which the item may be requisitioned and installed; and (3) the action to be taken as to salvage and repair of the part when defective.

Immediately below the description of the part is a symbol which is either a JAN designation, an AN number, or a manufacturer's part number. Components which are frequently replaced such as tubes, resistors, and capacitors usually have JAN designations. The interpretation of these symbols as applied to fixed resistors and capacitors is given in the following section.

JAN Designations and Color Codes for Resistors and Capacitors

Type designations consisting of combinations of letters and numbers are used to identify JAN type resistors and capacitors.

These designations indicate, in accordance with a code, the important electrical and physical characteristics of the part to which they refer. Where space limitations do not permit the type designation to be marked on the part, either color bands or bands and dots are used to indicate the electrical characteristics. A summary of the system of fixed resistor and fixed capacitor designation is given below. (This

information is also contained in NavPers 10087, *Basic Electronics*.)

FIXED COMPOSITION RESISTORS.—The type designation of fixed composition resistors is formed as in the example:

RC	40	BF	243	J
(a)	(b)	(c)	(d)	(e)

(a) COMPONENT. Fixed composition resistors are identified by the letters RC as in the first two symbols of the example. The letter R stands for "resistor," and the letter C stands for the subclass "composition."

(b) STYLE. The style is indicated by a two-digit symbol which identifies the power rating, physical shape, and size.

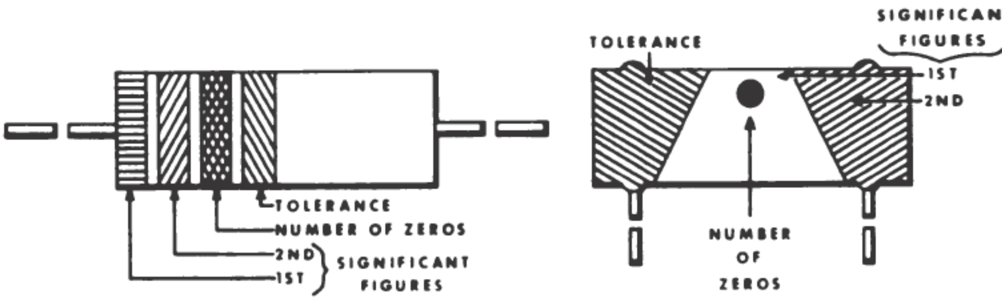
(c) CHARACTERISTICS. A two-letter symbol gives the characteristics of the resistor. The first letter denotes whether the element is insulated and also its moisture resistance. The second letter designates the resistance-temperature characteristic. (The interpretations of the symbols for style and characteristics can be found in JAN–R–11.)

(d) RESISTANCE VALUE. The resistance value in ohms is indicated by a three-digit symbol. The first two digits are the first two figures of the resistance value in ohms. The final digit specifies the number of zeros which follow the first two figures. The resistance value of the example is 24,000 ohms since the (d) part of the designator is 243.

(e) RESISTANCE TOLERANCE. The resistance tolerance is expressed by a percent figure preceded by the symbol "plus-or-minus." In the designator, this is denoted by a letter as follows:

Letter	*Tolerance*
J	$\pm$ 5 percent
K	$\pm$10 percent
M	$\pm$20 percent

COLOR CODE.—The resistance and the resistance tolerance of fixed composition resistors are indicated by the position and color of bands or of body color, end color, and dot color, in accordance with the sketches shown in figure 4–2.



(A) RESISTOR WITH AXIAL WIRE LEADS. (B) RESISTOR WITH RADIAL WIRE LEADS.

Figure 4-2.—Color code for fixed resistors.

The colors are associated with the values shown in table 4-1.

Consider as an example an axial-lead resistor with bands colored red, orange, yellow, and gold, reading from left to right. The red band signifies a first digit of 2. The orange band shows the second digit to be 3. The yellow band, signifying 4, means that four zeros are to be added to the first two digits, giving a resistance value of 230,000 ohms. The gold band is the tolerance indication and means ±5 percent.

As an example of the code applied to a radial-lead resistor,

Table 4-1.—Resistor color values.

Body First Band		End Second Band		Dot Third Band		End End Band	
Color	*Value*	*Color*	*Value*	*Color*	*Value*	*Color*	*Tolerance*
Black	0	Black	0	Gold	0.1	Gold	(J) ±5%
Brown	1	Brown	1	Silver	0.01	Silver	(K) ±10%
Red	2	Red	2	Black	None	None	(M) ±20%
Orange	3	Orange	3	Browr	0		
Yellow	4	Yellow	4	Red	00		
Green	5	Green	5	Orange	000		
Blue	6	Blue	6	Yellow	0000		
Violet	7	Violet	7	Green	00000		
Gray	8	Gray	8	Blue	000000		
White	9	White	9	Violet	0000000		
				Gray	00000000		
				White	000000000		

suppose there is a body color of orange, an end color of blue, a green dot, and an end color of silver. The interpretation is as follows:

The orange body signifies a first digit of 3.

The blue end signifies a second digit of 6.

The green dot means 5 zeros must be added.

The silver end indicates that the tolerance is plus-or-minus 10 percent.

The resistance value is 3,600,000 ohms, $\pm 10\%$.

FIXED MICA CAPACITORS.—The JAN designation of fixed mica-dielectric capacitors may be illustrated by the following example:

CM	20	A	050	M
(a)	(b)	(c)	(d)	(e)

(a) COMPONENT. All fixed mica-dielectric capacitors represented by the JAN designation are identified by the letters CM as the first two symbols of the designator.

(b) CASE. The case designation is a two-digit number which is used to identify the type of case, both in size and shape. (The interpretation of these symbols is given in JAN–C–5.)

(c) CHARACTERISTICS. The characteristics symbol is a single letter which refers to the temperature coefficient and the maximum capacitance drift.

(d) CAPACITANCE VALUE. The value of the capacitor in micromicrofarads is indicated by a three-digit number. The first two digits are the first digits of the capacitance value. The final digit specifies the number of zeros which follow the first two digits.

(e) CAPACITANCE TOLERANCE. The tolerance, expressed as a percentage preceded by a plus-or-minus sign, is designated by a letter, as follows:

Designation letter	*Tolerance*
G	$\pm 2\%$
J	$\pm 5\%$
K	$\pm 10\%$
M	$\pm 20\%$

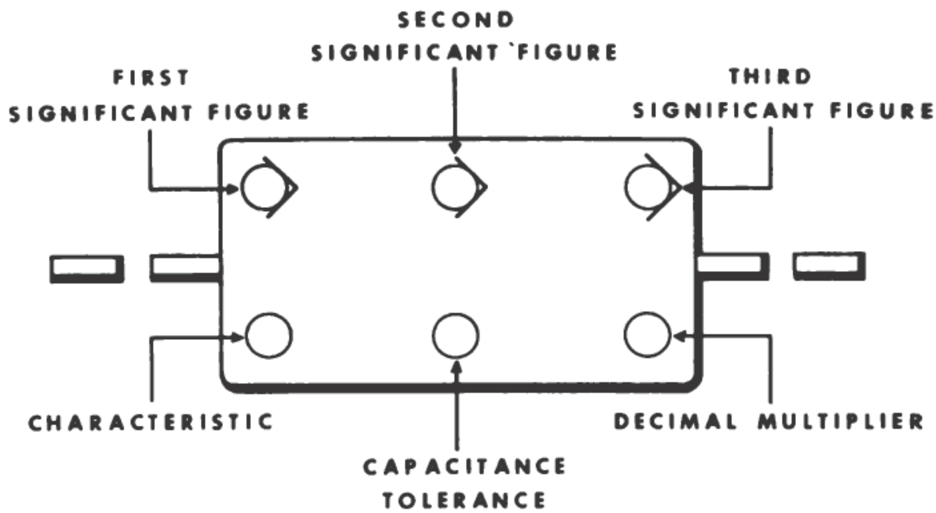


Figure 4–3.—Color code for fixed mica capacitors,

The color code for JAN mica capacitors is shown in figure 4–3.

The colors are interpreted as in table 4–2.

The letters in the column headed "Characteristics" have the following meanings:

A Ordinary mica bypass capacitor.

B Similar to A but with a low-loss case.

Table 4–2.—Color code for mica capacitors.

Capacitance			Tolerance	Characteristics
Color	Significant Figure	Decimal Multiplier		
Black	0	1	20%(M)	A
Brown	1	10	1%	B
Red	2	100	2%(G)	C
Orange	3	1,000	3%	D
Yellow	4	10,000	4%	E
Green	5	100,000	5%	F
Blue	6	1,000,000	6%	G
Violet	7	10,000,000	7%	
Gray	8	100,000,000	8%	
White	9	1,000,000,000	9%	
Gold		0.1	5% (J)	
Silver		0.01	10% (K)	

C Bypass or silver mica (temperature coefficient of ± 200 parts per million per degree C.).

D Silver mica (± 100 parts per million per degree C.).

E Silver mica (0 to 100 parts per million per degree C.).

F Silver mica (0 to 50 parts per million per degree C.).

G Silver mica (0 to -50 parts per million per degree C.).

The expression "± 200 parts per million per degree C." means that the capacitance value may increase or decrease 200 micromicrofarads for each million micromicrofarads in the rated value when the temperature changes by one degree centigrade.

FIXED CERAMIC-DIELECTRIC CAPACITORS.—The designation of fixed ceramic capacitors indicates the component, the style, the characteristics, the capacitance value, and the capacitance tolerance of the capacitor. The type designation is formed as follows:

CC	25	SL	100	G
(a)	(b)	(c)	(d)	(e)

(a) COMPONENT. Fixed ceramic capacitors are identified by the symbol, CC. The first letter indicates a capacitor and the second signifies those capacitors with ceramic dielectrics.

(b) STYLE. The style designation is a two-digit symbol which identifies the particular shape and size of the capacitor.

(c) CHARACTERISTICS. The characteristic designation is in the form of two letters. The first letter specifies the temperature coefficient of capacitance. The second letter indicates the tolerance of the temperature coefficient. (The symbols used to designate style and characteristics data are interpreted in JAN–C–20.)

(d) CAPACITANCE VALUE. The capacitance value of the capacitor in micromicrofarads is indicated by a three-digit number. The first two digits are the first two digits of the capacitance value in micromicrofarads, and the final digit specifies the number of zeros which follow the first two digits. Where more than two significant figures are required, additional digits may be used, the last digit always indicating the number of zeros.

If the capacitance value must be expressed as a decimal fraction, the decimal point is indicated by the letter R, and there is no indication of a number of zeros to follow the significant figures. Thus, 1R5 indicates a value of 1.5 micromicrofarads.

(e) CAPACITANCE TOLERANCE. The capacitance tolerance expressed as a "plus-or-minus" quantity is designated by a letter as shown in table 4–3. Where the indicated value of capacitance is greater than 10 micromicrofarads, the tolerance is expressed in percent. When the value is 10 micromicrofarads or less, the tolerance is expressed in micromicrofarads. The table of tolerances is as follows:

Table 4–3.—Table of tolerance for ceramic-dielectric capacitors.

Letter Symbol	Percent	mmfd.
C		0.25
D		0.5
F	1	1.0
G	2	2.0
J	5	
K	10	
M	20	

The color code for ceramic capacitors is shown in figure 4–4.

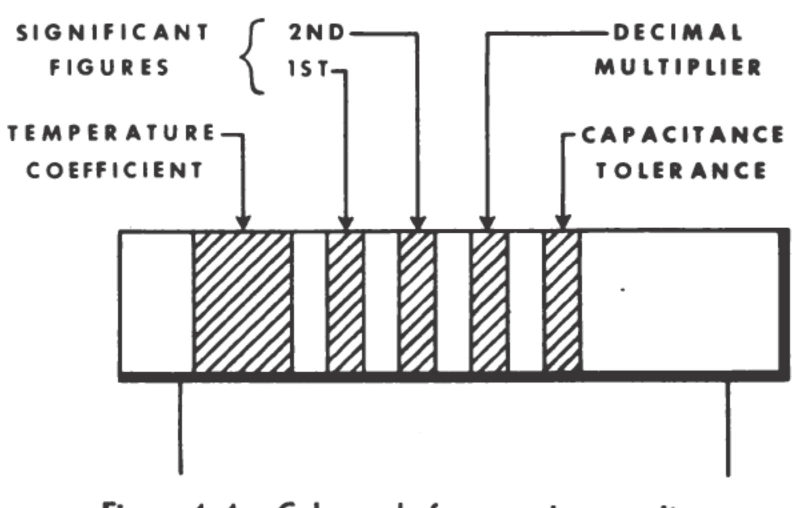


Figure 4–4.—Color code for ceramic capacitors.

The color code applied to the color bands in the figure is given in table 4–4.

Table 4–4.—Color code for ceramic capacitors.

Color	Significant Figure	Multiplier	Tolerance of Capacitance: Capacitors of Value greater than 10 mmfd. in percent	Tolerance of Capacitance: Capacitors of 10 mmfd. or less in mmfd.	Temperature Coefficient Parts per million per degree, Centigrade.
Black	0	1	20 (M)	2.0 (G)	0
Brown	1	10	1 (F)	----------	−30
Red	2	100	2 (G)	----------	−80
Orange	3	1,000	----------	----------	−150
Yellow	4	10,000	----------	----------	−220
Green	5	100,000	5 (J)	0.5 (D)	−330
Blue	6	1,000,000	----------	----------	−470
Violet	7	10,000,000	----------	----------	−750
Gray	8	0.01	----------	0.25 (C)	+30
White	9	0.1	10 (K)	1.0 (F)	+550

Wiring Color Code

In addition to the color codes used for resistors and capacitors, a system of coding the conductors in electronic and electrical equipment has been adopted for military applications. This system is called the MILITARY STANDARD WIRING COLOR CODE. Use of the code provides a means of rapid identification of the numerous conductors associated with electronic and electrical circuits. According to this code, the colors to be used in the conductor insulation are as follows:

Grounds, grounded elements, and returns --- Black
Heaters, or filaments (ungrounded leads) --- Brown
Power supply positive leads (B plus) --- Red
Screen grid circuits --- Orange
Cathode circuits --- Yellow
Control grid circuits --- Green
Plate circuits --- Blue
Power supply negative leads --- Violet

A-c power leads	Gray
Miscellaneous	White

The leads are coded either with a solid color or a combination of a solid color and a narrow strip, or tracer.

The wire issued to field activities for replacement purposes is limited to uncolored and white, and other colors are reserved for issue to overhauling activities.

When it is necessary to replace defective wiring in electronic, electrical or accessory equipment, white wire of the correct size is used and the color (or colors) of the original lead is written on the replacement. This is done either with a stamping machine, or if a machine is not available, by writing the wire letter code or the color on a paper strip and attaching the strip to the lead by means of cellulose tape.

The color code is applied to the replacement lead as follows: The first color stamped or written is the body color of the original; the second color indicates the tracer. The spelled out colors are separated by a dash. For example, if the wire to be replaced is a blue wire with a green tracer, the wire is marked "BLUE–GREEN."

On long wires, the color-words are written at intervals not greater than three inches along the entire length of the wire. If the wire is shorter than three inches, the spelled out colors are stamped or written at least once on the wire.

The temporary white wires are replaced with wire colored according to the code at overhaul activities.

Wattage Ratings of Replacement Resistors

When a resistor must be replaced under emergency conditions, one of the important considerations in selecting the replacement is the wattage value. In general, the wattage rating is a measure of the ability of the resistor to dissipate heat, and the value is related to the physical size of the resistor.

The selection of a safe wattage value is based on a consideration of the working conditions of the resistor in the circuit. Consider as an example, the replacement of an 850-ohm resistor with one of equal ohmic value but which has

a tolerance of ± 20 percent. Suppose the normal voltage existing across the resistor is 40 volts. Because of the 20 percent tolerance, the actual resistance of the replacement may be as much as 1,012 ohms or as little as 680 ohms. Taking the lesser value as the more unfavorable from a heat-dissipating standpoint, the power that may be developed in the resistor under circuit conditions is found as follows:

$$W = \frac{E^2}{R}$$

$$W = \frac{40 \times 40}{680}$$

$$W = 2.35 \text{ watts, approximately}$$

The resistor should be capable of dissipating from 1.5 to 2 times the power actually encountered; and in the example, this value is not more than 4.7 watts. Since a 5-watt resistor is the next standard size above the 4.7-watt value, this is a desirable wattage rating for the replacement.

Under emergency conditions, it is sometimes necessary to combine resistors in series or in parallel to give some desired resistance value. When this is done, care should be taken to avoid a voltage distribution (or current distribution) which causes any low-wattage resistor in the combination to dissipate an excessive amount of heat. For example, suppose two 10-watt resistors of 1-ohm value were combined in series with a 2-watt resistor with an ohmic value of 10 ohms. The total wattage developed when the series combination is connected across 12 volts is 12 watts. But the power dissipated by the 10-ohm, 2-watt resistor is 10 watts, a value far in excess of its capabilities. It is necessary to consider each resistor in the combination and select a wattage value based on the voltage developed across the individual unit.

AN ELECTRICAL CONNECTORS

The purpose for which AN electrical connectors are designed is to provide a detachable means of coupling between major components of electrical and electronic equip-

ment. These connectors are constructed to withstand the extreme operating conditions imposed by airborne service. They must make and hold electrical contact without excessive voltage-drop despite extreme vibration, rapid shifts in temperature, and great changes in altitude.

AN connectors vary widely in design and application. Each connector consists of a plug assembly and a receptacle assembly. The two assemblies are coupled by means of a coupling nut, and each consists of an aluminum shell containing an insulating insert which holds the current-carrying contacts. The plug is usually attached to a cable end and is the part of the connector on which the coupling nut is mounted. The receptacle is the half of the connector to which the plug is connected and is usually mounted on a part of the equipment.

There are wide variations in shell type, design, size, layout of contacts, and style of insert. Eight types of connector shells are shown in figure 4–5.

Connector 3100 is a wall mounting receptacle. It is intended for use with conduit to eliminate the necessity of installing conduit boxes.

Connector 3101 is a cable connecting receptacle, and is used with cable or in other installations where mounting provisions are not required.

AN 3102 is a box mounting receptacle, and is intended for use where a detachable connection is required on a shielded box or unit of equipment.

AN 3106 is a straight plug which is used when circuits are to be connected where space limitations are not critical. It consists of a front shell (usually referred to as an "insert barrel"), a coupling ring, the insert, an insert retaining device, and a rear shell.

AN 3107, a quick disconnect plug, is used where very rapid disconnections must be made. A special coupling device is used instead of a coupling ring; otherwise it is similar to AN 3106.

AN 3108, a 90-degree-angle plug, is similar in construction to AN 3106 except that the rear shell provides a right-angle bend which is required where space is limited.

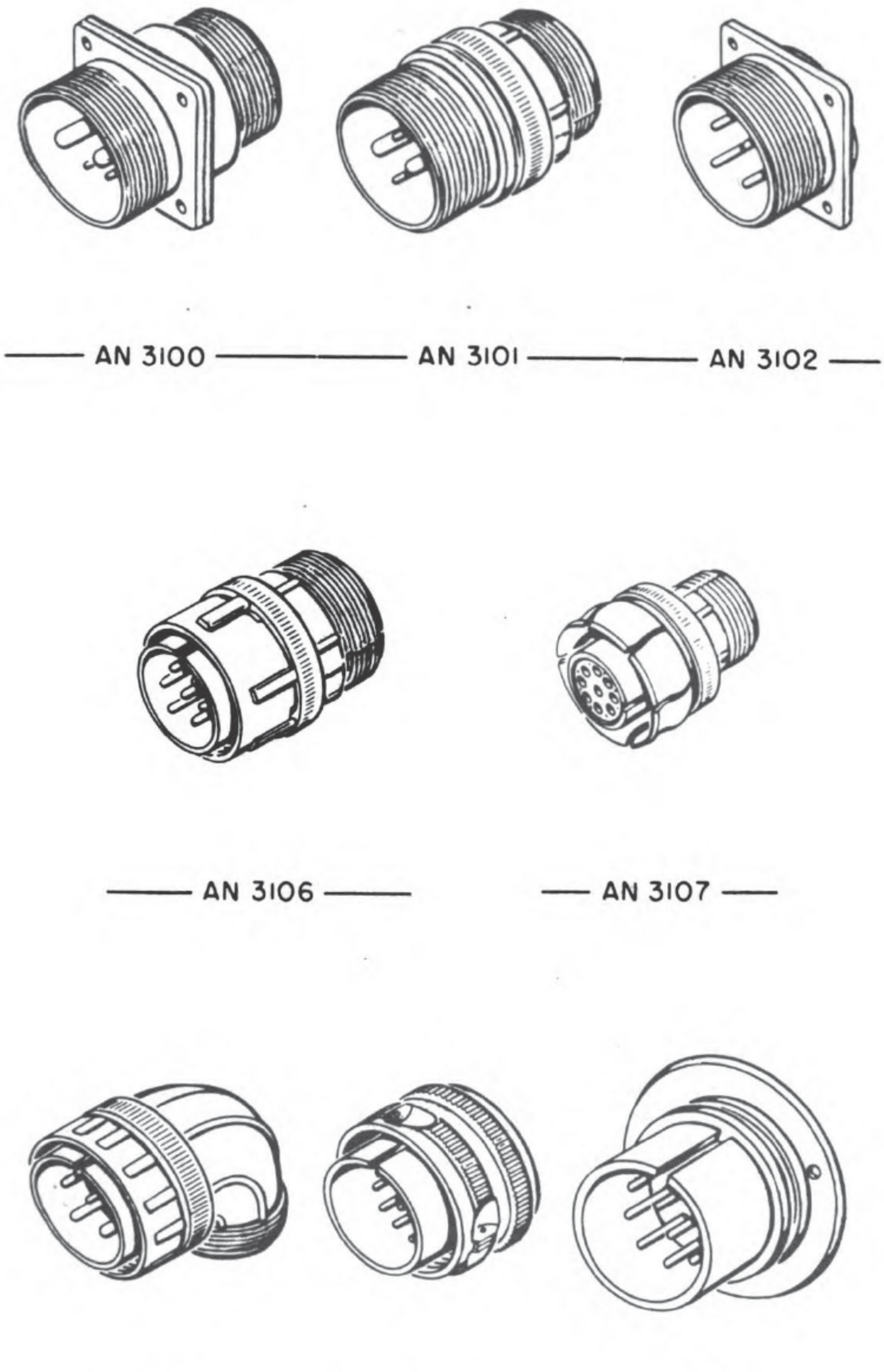


Figure 4-5.—AN connector shells.

The connectors AND 10066 and AND 10459 are integral mounting receptacles. The shells are made as integral parts of the electrical equipment housings on which the connectors are mounted.

The shells of AN connectors are made in eight types, each for a particular kind of application. A letter designation is used in the AN number to indicate the shell design, as in AN 3106M, where M is the shell type indicator. The shell indicators are as follows:

- A Solid shell
- B Split shell
- C Pressurized type
- D Sealed construction
- F Vibration resistant
- H Flame barrier shell
- K Fireproof construction
- M Moisture resistant shell

Solid shell connectors are used where no special requirements, such as fireproofing or moistureproofing, must be met. The rear shells are made from a single piece of aluminum.

Split shell connectors allow maximum accessibility to soldered connections. The rear shell is made in two halves, either of which may be removed.

Pressurized connectors provide a pressure-tight feed-through for wires that pass through walls or bulkheads of pressurized compartments in high altitude airplanes. The contacts are usually molded into the insulator and the shell is spun over the assembly to seal the bond.

Sealed connectors are employed in equipment that is sealed and operated under gas pressure. These connectors include a glass-to-metal seal and have either special rubber inserts or a cementing compound applied to the insert.

Vibration resistant connectors are designed for use in equipment that is subjected to intense vibrations in installations on or near reciprocating engines.

Flame barrier and fireproof connectors are both made under specifications which require that the connector maintain effective electrical service for a limited time even when exposed to fire. The inserts are made of a ceramic material, and special crimp type contacts are used.

Moisture resistant connectors are a comparatively recent

development in AN connectors. They consist of a combination of the features of the solid shell, the pressurized, and the vibration resistant types. The component parts of this kind of connector are shown in figure 4–6.

Each connector is given an identification symbol which is called the AN number. This symbol indicates the shell type, the shell design, the size, the insert type, the insert style, and the insert position. An example is the designator.

AN 3100 A–16–11 PX.

The letters AN (sometimes AND) form the Army-Navy prefix. The number 3100 indicates the shell type and identifies the connector as one of the types shown in figure 4–5.

The letter A indicates a solid shell connector. The number 16 is the shell size.

The number 11 is a designation of the insert arrangement used in the connector.

The letter P means that the insert is a pin, or male, insert. The letter S is used to indicate a socket, or female, insert.

The concluding letter, X, is a designation of the insert position. Connectors specially designed for a particular application sometimes have nonstandard contact, or insert, positions. Four positions of the inserts are employed, and these are called W, X, Y, and Z. Each letter refers to an angle by which the insert is rotated from the standard position. When the standard position is employed, no letter is shown at the end of the AN designation. For further information together with illustrations of the various types employed, the reader is referred to the publication, AN 03–5–90, *Operation and Service Instruction AN Connectors*.

Service, Inspection, and Maintenance of AN Connectors

AN connectors are generally inspected when the major units containing them are inspected. During this inspection, the mating parts of the connectors are separated and the contacts examined for corrosion. If corrosion is present, the surfaces are cleaned with a brush or clean rag. The cleaning is finished with alcohol or some noncorrosive solvent. The

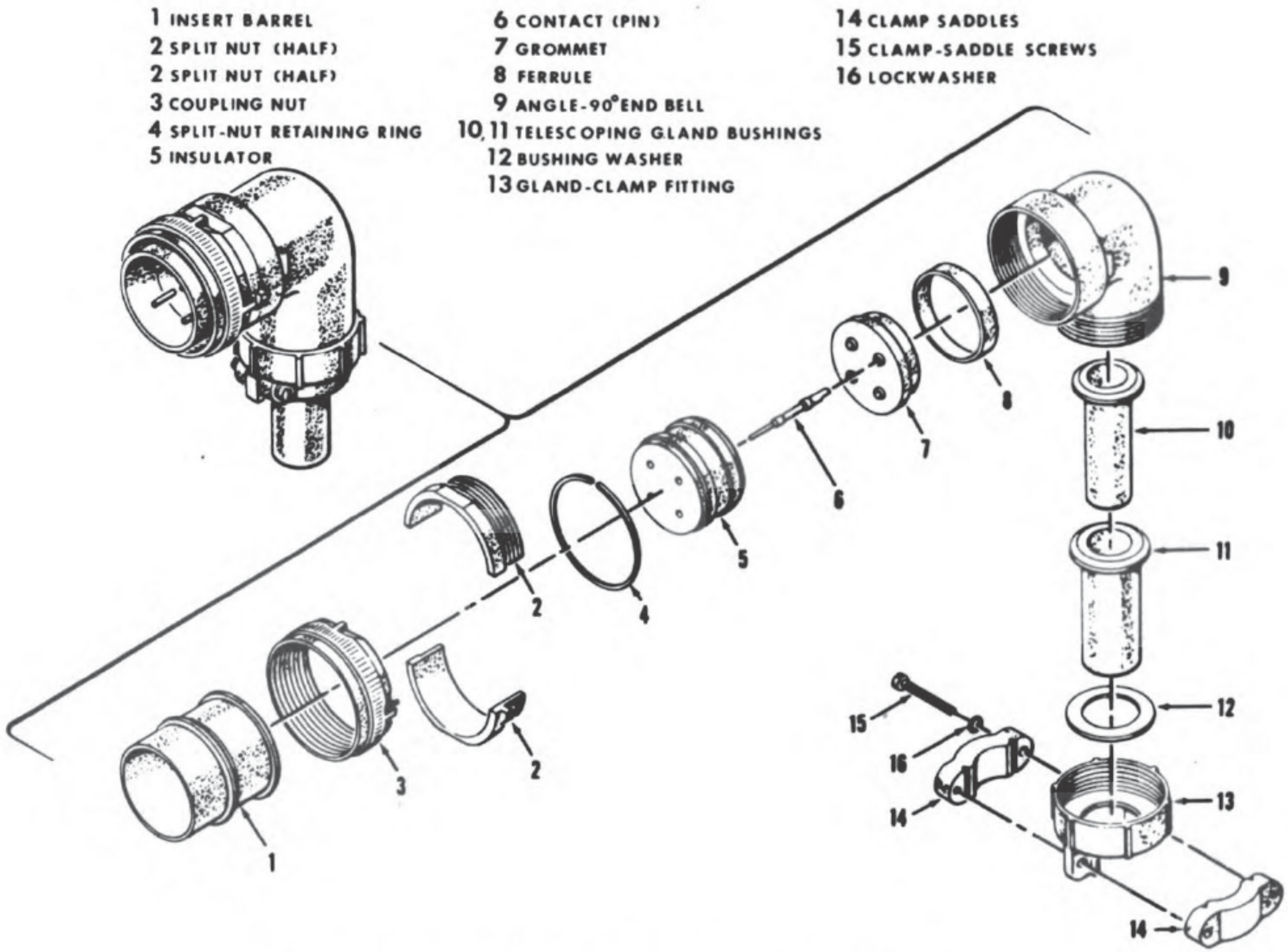


Figure 4-6.—Exploded view of connector AN 3108M.

coupling ring is inspected for battered threads, and the ring should be replaced if the threads are not in good condition. When attaching or detaching the connector, care should be taken to avoid damaging the coupling or bending the coupling ring.

During inspection, all cable conductors should be tested for electrical continuity with an ohmmeter. When open circuits are present they are usually found at the conductor terminations. If the break is not at the termination, the conductor should be replaced.

Short circuits are often caused by a frayed strand of one conductor touching the solder cup of another conductor at a cable ending. If this is the case, the frayed strand may be clipped. If the short is between two conductors, both must be replaced.

If the maintenance instructions covering the cable require that an insulation test be made, this is done with a Navy Type G Insulation Resistance Test Set or other similar tester.

AN connectors require no lubrication except for the coupling ring threads. These should be given a coat of antiseize compound when they are replaced after inspection.

Moistureproofing Electrical Connectors

Operating conditions are often such that ordinary electrical connectors must be given a moistureproofing treatment. The basis of moistureproofing is the application of a compound called THIOKOL to prevent corrosion, contamination, and electrical failure. This compound excludes liquids and reinforces the back of the connector, thereby reducing electrical failures caused by vibration. In addition, the moistureproofing treatment diminishes the chances of arc-over between the connnector pins.

Thiokol is a type of synthetic rubber. It is provided in kit form and is available through normal supply channels. The materials required for the treatment in addition to the kit are:

1. Paper towels or a sheet of plain white paper.

2. Masking tape or cellophane tape.

3. Dry cleaning solvent, Federal Specification PS-661 (Stock No. G51-C-1326-67).

4. Suitably sized O-ring seals.

5. A stiff bristle brush.

In preparation, the connector is first disassembled so as to expose both faces of the insert disks. The stiff bristle brush is then used to clean away all residue. Both faces of each insert disk are washed with cleaning solvent. At this time, the soldered connections of both plug and receptacle are inspected and any defective connections are resoldered.

A length of wire approximately 12 inches long should be soldered to any spare pin in the connector. This wire provides a means for attaching additional circuits through the connector to serve auxiliary equipment which may be added later.

After the sealing compound has been mixed according to the directions supplied with the kit, the plugs and receptacles are arranged on a table in such a position that gravity will draw the sealer to the bottom of the assemblies.

If the connectors do not have back shells, they must be fitted with a mold formed from masking tape or from cellophane tape. The mold is filled with the compound until at least ⅜ inch of the insulated wire is covered. The wires are then grouped in the manner desired and in a position which will not permit the compound to pour or spill. To insure that the entire connector assembly is sealed against fluid entering or collecting between the two parts, it is necessary that a rubber O-ring be fitted over the barrel of the plug to provide a seal when the two parts are engaged.

After the compound has been poured, the treated connector is allowed to stand until the sealer has become thoroughly cured. The curing time varies with the surrounding temperature; and in a temperature of 60 degrees F., this interval is about four days.

CABLES, TERMINALS, AND TERMINAL BLOCKS

In addition to his duties of maintaining purely electronic equipment, the aviation electronics technician is often required to fabricate and install cables in aircraft, to secure cables to terminal blocks, to attach terminals to cables, and sometimes to reroute existing cable installations in the aircraft. One of the primary items of information concerning aircraft wiring is concerned with cable identification.

CABLE IDENTIFICATION.—Aircraft cables are identified by a symbol consisting of letters and numbers, as in the symbol P2B4. Reading the designator from left to right, the code is interpreted as follows:

1. The circuit function is represented by a letter: the letter P in the example. The letters R, S, T, and X stand for radio, radar, special electronic equipment, and a-c circuits, respectively. The letters P, A, and L stand for power, armament, and lighting.

2. Each cable is assigned a cable number. In the example, P2B4, the cable number is 2. The same number is retained throughout the cable run from the power source to any piece of equipment, such as a switch. After leaving the switch the cable is then assigned a new number. The same number is retained between any two pieces of equipment joined by the cable and between one source of power and another. Cable numbers do not change at terminal blocks.

3. Each segment of cable between two terminals is given a segment letter. The segment letters run in sequence starting with a letter A. Segment letters change at terminal blocks. In the example, P2B4, the designator refers to the B segment of cable 2, which is a power-carrying cable. If cable P2B4 terminates on a terminal block, the cable leaving the block is then called P2C4. If the cable had terminated on a switch, which is a control point or piece of equipment, the cable leaving the switch would then be called P3A4.

4. The fourth symbol in the designator is a number representing the cable size.

5. In addition to the basic coding there are more code letters which assist in further identification. The letter N

is used as a last letter to indicate a cable that is attached to ground or to a negative terminal, as in P6A8 N. A circuit designation letter is sometimes used to identify a particular circuit, as in R L 15 F 18, where R stands for radio, L is the circuit designator and means LIAISON. The circuit designation always follows the circuit function letter.

Where two or more identical items of equipment are installed in the same aircraft, the unit number (1, 2, 3, or 4) may be prefixed to distinguish between corresponding cables of the identical items. This requirement is mandatory for equipment listed under circuit functions letters R, S, and T. An example of the unit number is the designator 2 R 16 B 14, where 2 is the unit number.

INSTALLATION OF TERMINALS ON CABLES.—Wires are attached to terminals either with solder or by means of solderless, crimp-on terminal lugs. A crimping tool is required for solderless connection, the use of which is illustrated in figure 4–7.

A representative field procedure for soldering the wires of a cable to the terminals of an electrical connector follows:

1. Disassemble the connector to allow access to the terminals and devise a means of holding the connector so that both hands are free.

2. Strip the wire end with a wire stripper or knife. If a knife is used, avoid cutting or nicking the wire strands. Tin the bare wire end.

3. Place insulating sleeving (spaghetti) over the wires and run the wires through the connector assembly and coupling nuts.

4. See that all surfaces are clean.

5. Flow rosin-core solder into the connector terminals. Insert the wire into the terminals, holding the tip of the soldering iron against it. As the solder melts, push the wire into the cavity. Hold the wire steady while the solder cools. Care should be taken to avoid injuring the connector insulation with the soldering iron.

6. When the joint has cooled, slip the insulating sleeve over the soldered joint. When all the wires in the cable have

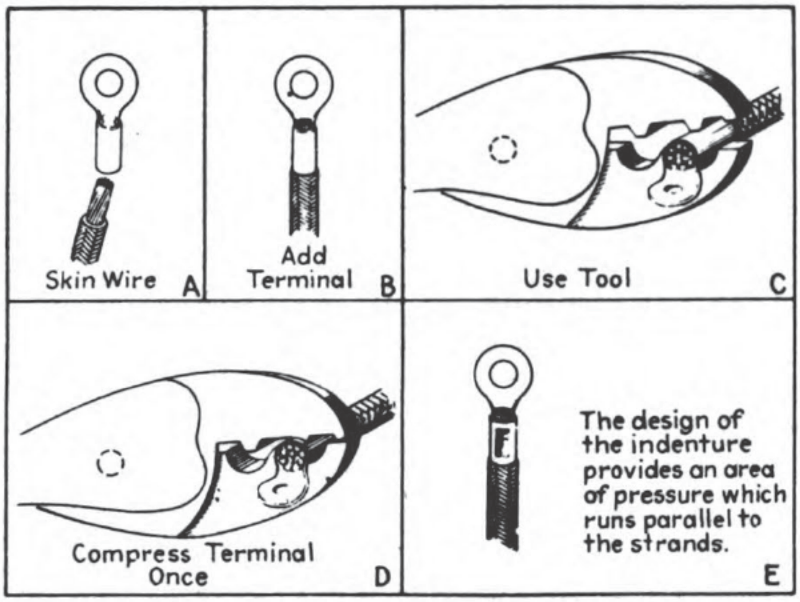


Figure 4–7.—Crimping a terminal to a wire.

been soldered, cooled and insulated, tie the individual wires together with string just back of the sleeve endings. This helps to prevent undue strain on the soldered joints when attaching or detaching the cable plug and the receptacle. The installation of the insulated sleeves is shown in figure 4–8.

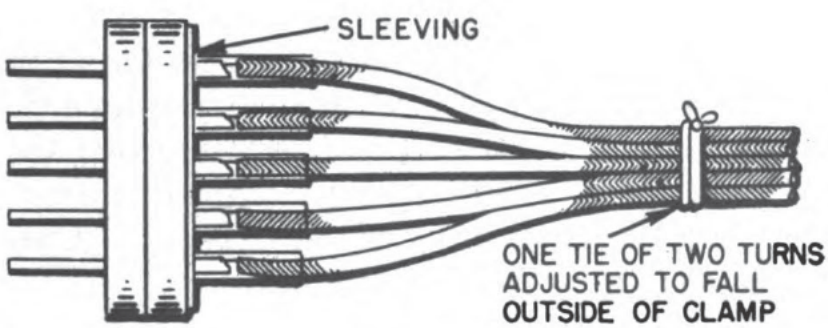


Figure 4–8.—Installation of insulating sleeving for connectors.

7. Assemble the connector.

SAFETY WIRING OF PLUG CONNECTORS.—A typical method of safety wiring plug connectors is shown in figure 4–9. The safety wire should be as short as practicable and must be installed in such a manner that the pull on the wire is in the direction which tightens the nut on the plug.

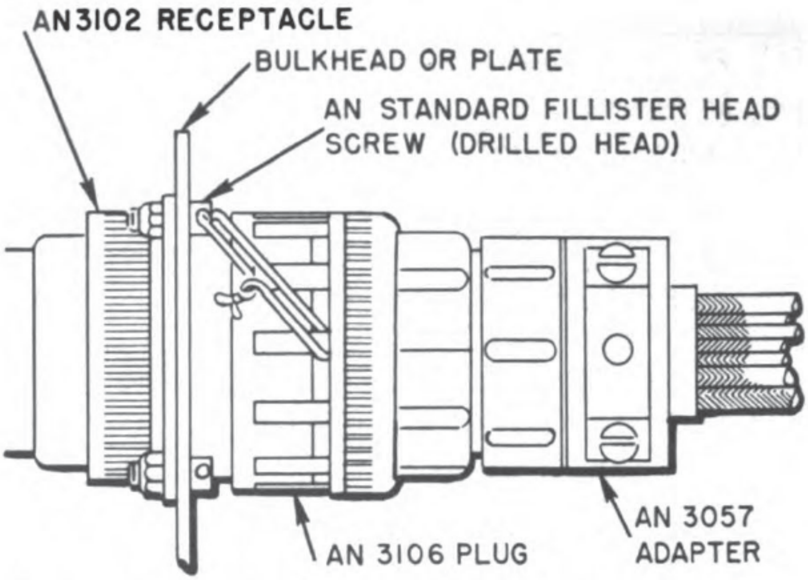


Figure 4–9.—Safety wiring attachment for plug connector.

HARNESS LACING.—The accepted method of lacing cable harness is shown in figure 4–10.

Continuous lacing is applied only to cables within terminal panels and junction boxes. Long runs of cable between panels are supported either by a strap-type clamp, shown in (A) of figure 4–11, or by an AN742 clamp, illustrated in (B) of the same figure.

The preferred method of supporting cables for all types of runs is with AN742 clamps. When the strap-type clamp is used, precautions must be exercised to insure that they will hold the cables firmly away from lines, surface control cables, pulleys, and all movable parts of the airplane. (Only Adel 674–3–6FR strap-type clamps are approved.)

When cables pass through lightening holes, the installation should conform to the examples shown in figure 4–12. In each case, the cable is held firmly by an AN742 cable clamp and an AN743 bracket. The cable should be routed well in the clear of the edges of the lightening hole, to avoid any possibility of chafing of the insulation.

SECURING THE CABLE TERMINALS ON TERMINAL BLOCKS.—Two methods of attaching cable terminals to terminal blocks are illustrated in figure 4–13.

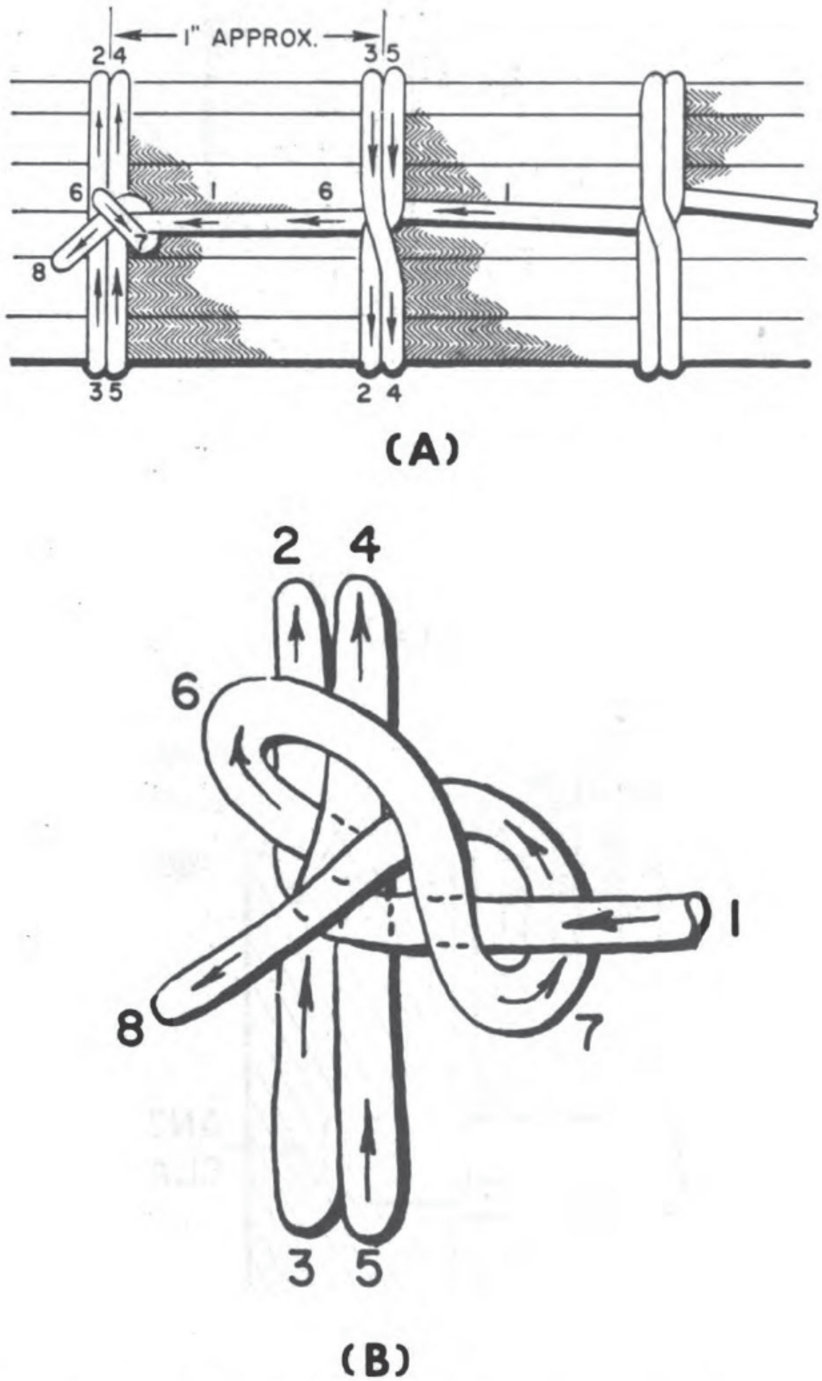


Figure 4–10.—(A) Continuous lacing; (B) terminating knot.

In (A) of the figure a standard nonlocking nut is used. In this method of installation, the use of a lockwasher (AN935) is necessary. The preferred method is shown in (B) of the figure. An anchor nut, or self-locking nut, is used and the lockwasher is omitted. The use of anchor nuts is especially

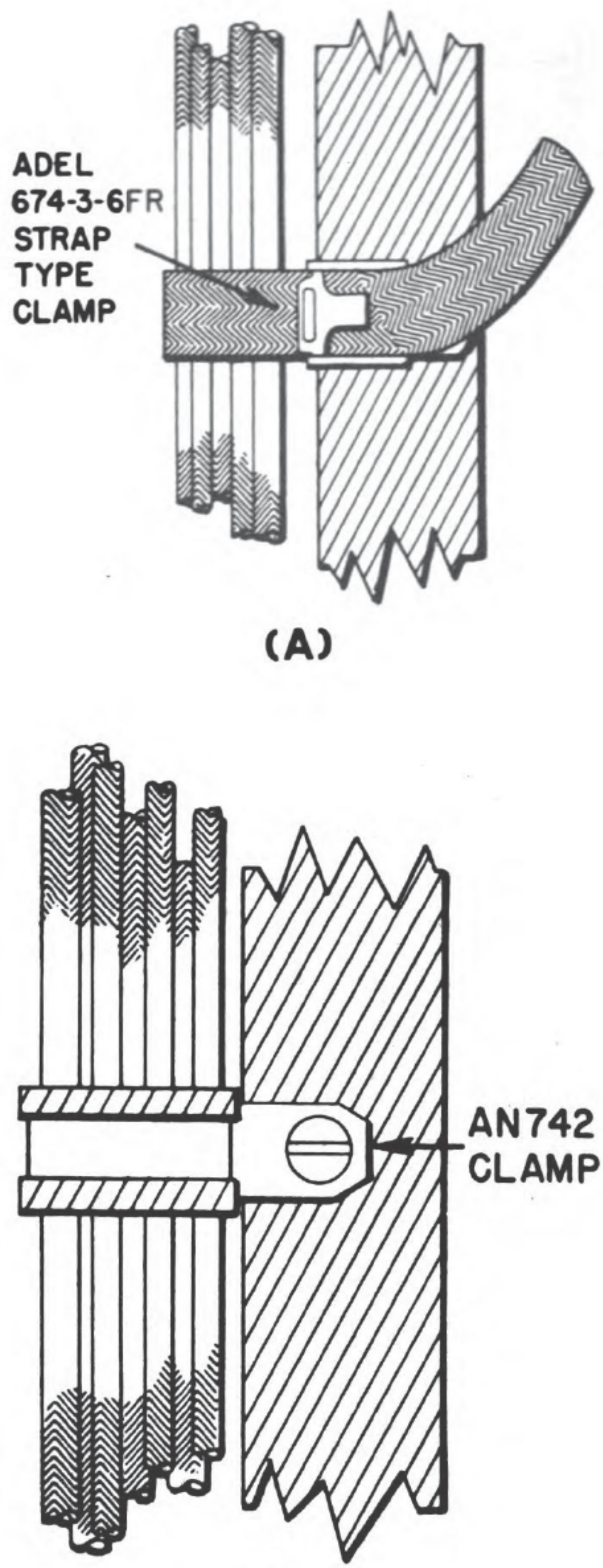


Figure 4-11.—(A) Strap-type clamp; (B) AN742 clamp.

desirable in areas of high vibration. In both installations, it is required that a flat washer (AN960) be employed as shown in the drawings.

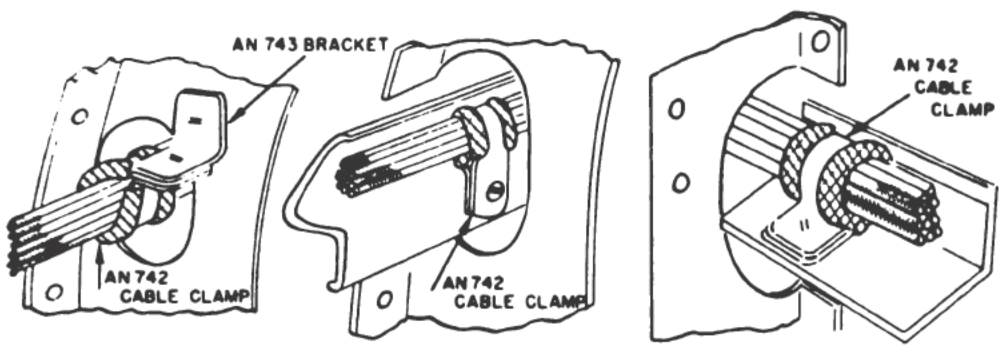


Figure 4-12.—Routing cables through lightening holes.

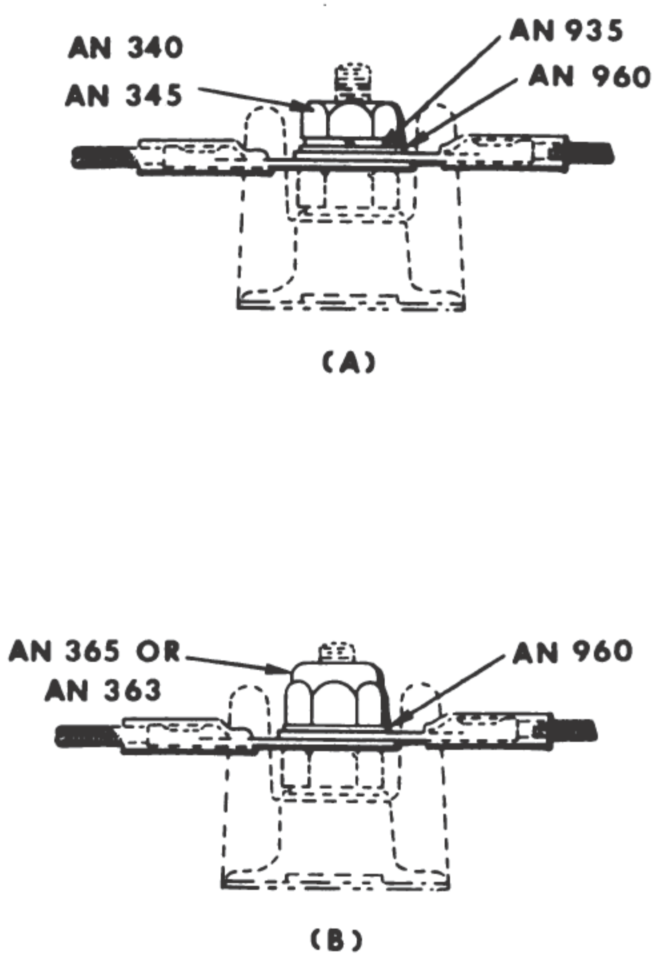


Figure 4-13.—Installation of cable terminals on terminal block.

MAINTENANCE OF COMMUTATORS AND SLIPRINGS

The commutators of aircraft motors, dynamotors, and d-c generators are inspected and cleaned at regular intervals as specified in the *Handbook of Service Instructions* accompanying the equipment.

The motor, dynamotor, or generator is removed in accordance with the instructions. Dust and dirt are cleaned from the machine and from the end covers with clean, dry, compressed air, or with a soft brush.

The electrical brushes are then loosened and carefully removed and inspected. The location and position from which each is taken should be noted so that the brush can be replaced in the correct position upon reassembly. If the brushes bind in the brush boxes, they may be wiped with a clean cloth. If this does not suffice, they should be thinned down with No. 0000 sandpaper. Care should be taken to avoid letting the sandpaper touch the contact surfaces of the brushes. The contact edges must not be rounded or chipped, and any loose abrasive or carbon dust should be carefully removed. If the brushes are cracked, damaged, or worn excessively, they must be replaced. When new brushes are installed, the procedure should be in accordance with the instructions for brush seating provided with the specific equipment.

After inspection of the brushes, the commutator is checked for excessive wear, dirt, or any visible defect. If the commutator surfaces are dirty, they may be cleaned with a lint-free cloth moistened with a suitable cleaning solvent. After cleaning, the surfaces are carefully wiped dry. Finger-marking the commutator surfaces should be avoided.

A highly polished commutator surface is desirable, but a dark-colored surface should not be mistaken for a burned commutator.

Slight pitting of the commutator can be removed by the use of commutator dressing sticks of pumice grade, followed by polishing with canvas cloth.

When commutators become badly worn or scored, they

must be refinished. This can be done only at a properly equipped repair station.

The sliprings of a-c machines must be inspected periodically for smoothness of surface, diameter of the rings, and alinement of the rings on the shaft.

In routine maintenance of sliprings, cleaning and polishing is accomplished by using No. 0000 sandpaper or some finer grade. Emery cloth or coarse sandpaper should never be used. All sand particles should be blown from the rotor with dry compressed air after cleaning.

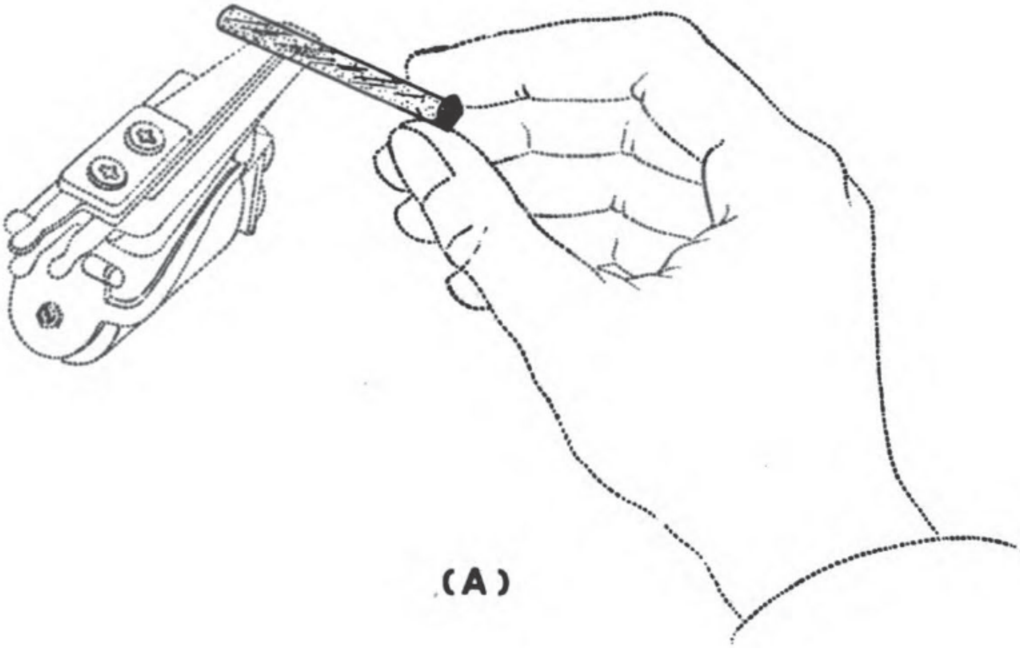
RELAY AND SWITCH CARE

Relays seldom require servicing unless a short circuit has caused the contacts to be burned and pitted, or unless damage has resulted from rough handling or improper treatment. When cleaning and adjusting the relay, it should be handled as if it were an expensive watch or a delicate meter.

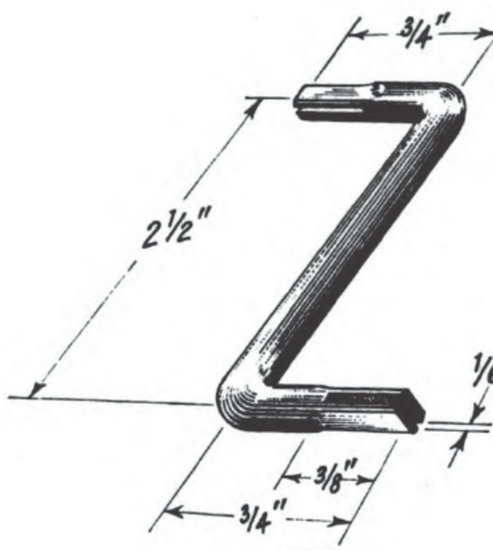
Relays can be ruined by the use of sandpaper or emery cloth for cleaning the contacts. When the contacts are dirty, the condition may be remedied by the use of a burnishing tool. Two common types of burnishing tools are stocked at naval supply activities. One of them, Stock No. R41–T–3080, is $2\frac{33}{64}$ inches in length; the other, Stock No. R41–T–3086, is 5 inches long. Either can be obtained through regular supply channels. The burnishing tool is regularly cleaned with alcohol. The surfaces used to burnish the relay contacts should not be touched with the fingers prior to use. The appearance of this tool is shown in (A) of figure 4–14.

When relays contain bent contacts, no attempt should be made to straighten them with long-nose pliers. Such an attempt often causes further damage with the result that the entire relay must be replaced. Bent contacts can be effectively straightened by using a point bender. The bender can be made locally from 0.125 diameter rod stock according to the dimensions shown in (B) of figure 4–14.

Maintenance of the switches in most electronic equipment involves adjustment and cleaning. This adjustment and



(A)



(B)

Figure 4–14.—(A) Relay burnishing tool, (B) relay point bender.

cleaning follows the same procedure and use of the same tools employed for relays.

ANTIFRICTION BEARINGS

Antifriction bearings are either ball or roller bearings. These, especially ball bearings, are widely used in aircraft rotating electrical machinery such as dynamotors, inverters, generators, and motor generators. In modern electrical machines, extensive use of sealed bearing assemblies is made. This makes maintenance and lubrication very easy since sealed bearings are prelubricated and require almost no attention during normal operation of the machine in which they are installed.

As a guide to proper maintenance of ball bearings in dynamotors and other aircraft equipment, the detailed recommendations of the manufacturer as given in the *Handbook of Service Instructions* should always be followed. As an example of general maintenance procedure, the following is taken from the instructions for bearing care pertaining to the 5134–G12B aircraft generator.

The bearings used in this generator normally are replaced with new bearings whenever abnormal conditions occur. However, in the event that new bearings are not available, the bearings may be cleaned and relubricated as follows:

1. Wipe the outside of the bearings clean using a clean cloth.
2. Wash the bearings thoroughly in cleaning solution (Specification PS–661).
3. Blow the bearings with compressed air until dry. The bearings should not be rotated while washing or drying.
4. Relubricate by packing the bearing full with General Purpose Lubricating Oil (Military Symbol 2190).
5. With a clean wooden stick, dig out all grease that can be removed between the balls on both sides. This will leave the bearing about 25 percent full which is the maximum amount which should be used.

Excessive lubrication leads to bearing trouble, and an undue amount of grease in the slipring or commutator compartment of the machine may result. Brush and slipring

wear increases appreciably if a large amount of lubricant is present.

All bearings should be wrapped in clean oil paper immediately after wiping clean until they are to be used in reassembly of the machine.

In the inspection of ball bearings, the assembly is slowly rotated. Bearings showing pronounced stickiness or bumpy operation should be replaced. The bearings are inspected for cracks, rough or pitted surfaces, and damaged balls.

QUIZ

1. An Electronics Technician must be able to
   a. operate and analyze operation of electronic equipments
   b. isolate defective parts
   c. make appropriate replacement or repairs
   d. all of the above

2. Which of the following checks are in the most logical sequence for locating troubles in electronic equipments?
   a. Voltage, resistance, current
   b. Voltage, resistance, signal tracing
   c. Visual, voltage, resistance
   d. Visual, resistance, signal tracing

3. Relative to the proper performance of electronic equipments, which of the following methods provides the quickest method of isolating a faulty stage?
   a. Voltage measurement
   b. Resistance measurement
   c. Current measurement
   d. Signal tracing

4. A signal generator delivers 350 microvolts to the grid of an i-f amplifier, causing an output meter to indicate a reference value. When applied to the following grid, the signal generator voltage must be raised to 2,800 microvolts to furnish the same reference value. What is the gain of the stage?
   a. 7
   b. 8
   c. 9
   d. 10

5. When making stage gain measurements in receivers, how may the technician best determine the correct value of input voltage required from the signal generator?
   a. By computing the amount required to produce a 1.73-volt drop across a 300-ohm load
   b. By consulting the *Handbook of Service Instructions*
   c. By selecting a signal high enough to allow the avc system to function
   d. By increasing the output from the signal generator until the recommended gain value is obtained

6. Which stages of the ARR–15 receiver are located in the main signal path?
   a. Noise limiter, detector, exciter
   b. Noise limiter, mixer, r-f amplifier
   c. Detector, mixer, exciter
   d. Detector, r-f amplifier, CFI unit

7. How often should the dynamotor of the ARR–15 (and similar receivers) be partially disassembled and inspected?
   a. On preflight checks
   b. On daily checks
   c. On major checks (approximately every 100 hours)
   d. On all regular periodic checks on the aircraft

8. Which of the following statements is false?
   a. Parts not assigned a JAN or AN number are usually special parts.
   b. Source code symbols can designate which replacement parts may be obtained from salvage.
   c. A JAN or AN standard part should be replaced by a new part listed under the same number.
   d. Parts assigned a JAN or AN number can usually be replaced by parts which are closely similar.

9. A radial resistor which bears a black dot, yellow tip, and red body has an ohmic value of
   a. 240
   b. 24
   c. 42
   d. 420

10. The color code for a one-ohm axial resistor with a tolerance of 20 percent would be
    a. black, black, brown
    b. black, brown, black
    c. brown, black, black
    d. brown, black

11. The color code for a fixed mica, 25-mmfd. capacitor is
    a. red, green, black
    b. red, green, brown
    c. black, red, green
    d. red, black, green

12. The first and last color markings on a 10-mmfd. fixed ceramic capacitor, to indicate a temperature coefficient of -80 and a tolerance of 2 mmfd., would have to be
    a. black, red
    b. black, gray
    c. red, red
    d. red, black

13. If a typical i-f amplifier stage is to be wired in accordance with the MILITARY STANDARD WIRING COLOR CODE, which of the following would be incorrect?
    a. A blue lead between plate and i-f transformer
    b. A green lead between grid and i-f transformer
    c. An orange lead between B plus and i-f transformer
    d. A black lead between ground and i-f transformer

14. A 500-ohm resistor must be replaced with a unit which has a tolerance of 20 percent. If 48 volts is normally dropped across the original resistor, what would be the most satisfactory replacement wattage?
    a. 15 watts
    b. 10 watts
    c. 5 watts
    d. 7 watts

15. What type of AN connector is normally used when there are no space limitations?
    a. AN 10066
    b. AN 3102
    c. AN 3106
    d. AN 3107

16. What type of AN connector contains a pressurized type shell?
    a. AN 3100C
    b. AN 3101M
    c. AN 3102H
    d. AN 3106F

17. What letter represents the Cable Identification Symbol for radar wiring?
    a. T
    b. X
    c. R
    d. S

18. With reference to Cable Identification Symbols, which of the following statements is true?
    a. The letter "G" is used to indicate a cable that is attached to ground.
    b. Cable numbers change at terminal blocks.
    c. The fourth symbol in the designator indicates the cable size.
    d. Segment letters do not change at terminal blocks.

19. Which of the following statements is true?
    a. Lightening holes should never be fitted with rubber grommets before running cable through.
    b. Continuous lacing is normally applied to long runs of cable.
    c. AN742 clamps are preferred for all types of cable runs.
    d. A washer is not required when using anchor nuts on terminal board wiring.

20. The pitting in a dynamotor commutator should be removed by the use of
    a. size 00 sandpaper and canvas cloth
    b. dressing sticks of pumice grade
    c. a fine grade of emery cloth
    d. coarse sandpaper

CHAPTER 5

MAINTENANCE PUBLICATIONS

The primary duties of the aviation electronics technician consist of installing, adjusting, maintaining, and testing numerous kinds of electronic equipment. In the performance of these duties, he is guided and assisted by several types of publications. One of the most important of these is the set of handbooks written for each kind of electronic or electrical device. The handbooks provide the detailed information and the approved and recommended procedures pertaining to the specific kinds of equipment to which they apply.

A second important type of publication affecting electronic maintenance includes Electronic Material Bulletins and Electronic Material Changes. These often supplement the information contained in the handbooks which are necessarily written before wide field experience with the associated equipment has been accumulated. When, as a result of this experience, modifications and changes are necessary, these are directed and authorized by means of the Bulletins and Changes.

One of the important duties of the technician involves making accurate and detailed reports of equipment and component failure. These reports are made on Electronic Failure Report forms. By means of these and similar sources of information, material bureaus are guided in planning for adequate supplies of spare parts, in revising equipment contracts, and in evaluating equipment performance.

There are several other kinds of publications which apply

to maintenance personnel. Among these are the Section "R" Allowance Lists, Section "U" Allowance Lists, and the publications called Instructions and Notices. The Allowance Lists specify the types and quantities of equipment and material provided to support a particular item of equipment; and some of the Instructions and Notices apply to aviation electronic maintenance.

A source of information concerning available issues of equipment handbooks, OpNav Instructions and Notices, Bureau of Aeronautics Bulletins and Service Changes, Allowance Lists, and many other types of publications, is provided in the *Naval Aeronautic Publications Index*.

EQUIPMENT HANDBOOKS

For each model of airborne electronic equipment, four handbooks are prepared. These are: The *Handbook of Operating Instructions* (HOI), the *Handbook of Service Instructions* (HSI), the *Handbook of Overhaul* (O/H) *Instructions*, and the *Illustrated Parts Breakdown* (IPB). These handbooks contain the condensed results of countless tests and checks made to assist the technician and operator in getting the best possible performance from the equipment. The handbooks are authorized for publication by the Chief of the Bureau of Aeronautics and are printed in accordance with a prescribed arrangement.

Of the four handbooks listed above, the two most frequently used by technicians and operators are the *Handbook of Operating Instructions* and the *Handbook of Service Instructions*.

The *Handbook of Operating Instructions* contains information pertaining to the operation of the specific equipment and also the necessary checks and adjustments required for obtaining good operating conditions. These books are divided into the following sections: A general description of the equipment, the operating procedures, the operating checks and adjustments, and provisions for emergency operation of the system.

The *Handbook of Service Instructions* provides information concerning the preparation for use and the maintenance of

the specific equipment by Operational (Squadron), FASRon, or equivalent activities. The handbook is divided into seven sections as follows:

SECTION I, DESCRIPTION AND LEADING PARTICULARS.—This section gives a description of the equipment and the general principles of its operation. Included in the section is information on the interchangeability of components and any special electrical or mechanical characteristics of the system or components.

SECTION II, SPECIAL TEST EQUIPMENT AND SPECIAL TOOLS.—Listed in this portion of the handbook are all necessary special test equipment and tools (including test racks) which are used for making complete bench-tests of the system or the components. Any instructions necessary for modifying the test equipment for some special use or for the fabrication of special testing harness are also found in this section.

SECTION III, PREPARATION FOR USE AND RESHIPMENT.—This section is divided systematically, showing the method by which the particular equipment should be handled from the moment it is received until it is ready for use by the operator. The section contains general information on uncrating and assembling the equipment on the test bench or in the aircraft, removing it from the aircraft, and recrating it for shipment. Detailed descriptions of cable fabrication and the connections of cables to the components are also included. Applicable data on any checks and adjustments required during installation of the equipment is found in this section.

SECTION IV, THEORY OF OPERATION.—A general description of the particular system is presented first, and this is followed by the detailed explanations of the individual circuits. The general description is usually given from the viewpoint of signal development, and block diagrams are used to trace the signal-development path.

SECTION V, ORGANIZATIONAL AND OPERATIONAL MAINTENANCE.—This section provides the instructions essential for the maintenance of the equipment and indicates the maintenance activities which perform it. Included are the preflight

and postflight inspections and tests, the bench-test procedures, and the troubleshooting methods to be used by these activities.

SECTION VI, FIELD AND FASRON MAINTENANCE.—The instructions required for the servicing of the equipment at FASRON or Field maintenance levels are included in this portion. In addition to alinement and parts removal procedures, information is given for checking component functions by means of performance checks. Also contained in this section are systematic trouble isolation procedures which assist in localizing a defective part or component to a circuit or group of circuits, depending upon the nature of the equipment.

SECTION VII, DIAGRAMS.—In this section are contained all the necessary diagrams for the maintenance and interconnection of the system. These include complete schematic, wiring, voltage, and resistance diagrams of the system or its components for use in trouble analysis. Also included are cabling charts for connection of the equipment components.

The *Handbook of Overhaul Instructions* provides detailed information for overhauling the electronic equipment and components for which it is issued. This includes such procedures as disassembly, cleaning, repair, recalibration, testing, and any other steps necessary for complete overhaul. The handbook is issued primarily to overhaul activities because the nature of the work described is beyond the capacities and facilities of the Squadron and FASRon maintenance activities.

The *Illustrated Parts Breakdown* contains detailed illustrations and listings of the components and parts of the equipment for which it is issued. The main value of this book for the technician is its usefulness when ordering parts for replacement purposes.

Revisions are prepared and distributed when it becomes necessary to modify the handbook. When properly entered, the revisions serve to keep the book an official source of the latest information applicable to the equipment. The available handbooks and the revisions are listed in the *NavAer Publications Index* and its supplements. By making peri-

odic checks of these, it is possible to determine which revisions are current and should be included in the handbook.

ELECTRONIC MATERIAL BULLETINS AND CHANGES

Electronic Material Bulletins and Electronic Material Changes are issued by the Chief of the Bureau of Aeronautics to all aeronautical activities. The purpose of these publications is to put into effect technical data concerning airborne electronic and electrical material.

Electronic Material Bulletins are technical instructions. They pertain to the operation, inspection, alinement, and maintenance procedures of the equipment.

Electronic Material Changes promulgate technical instructions necessary for the addition, removal, or replacement of a part; modification to circuity, etc. Modification of electronic material is normally limited to modification of parts, subassemblies, assemblies, components, or complete equipments, and interconnecting wiring. (Electronic Material Changes are not used for substitution of complete systems.) The changes resulting from these instructions have negligible effects on the weight and balance of the aircraft or on the aircraft structure.

Electronic Material Bulletins and Electronic Material Changes specify the time at which compliance must be made to the instructions and also the manner in which it is to be made. These publications replace Technical Orders and Technical Notes insofar as electronics and electrical material are concerned.

NAVAL AERONAUTIC PUBLICATIONS INDEX

The *Naval Aeronautic Publications Index* (commonly called *NavAer Publications Index*) is a consolidated listing of all publications and forms which pertain to aeronautical activities. It is divided into three parts:

Part I—Numerical listing of all effective BuAer publications;

Part II—Table of publications relating to aircraft and equipment; and

Part III—Cross reference listing publications applicable to each aircraft and its component equipment.

Complete instructions for ordering all the publications listed is included in the Index. It is issued annually and revisions are published at periodic intervals during the year.

ELECTRONIC FAILURE REPORTS

Electronic Failure Reports are prepared and submitted for all failures or unsatisfactory conditions of electron tubes and electronic or electrical parts, equipments, or systems. These reports have been adopted for use by the Bureau of Aeronautics, the Bureau of Ships, the Bureau of Ordnance, and other Department of Defense activities.

The purpose of these reports is to provide the bureau concerned with up-to-date information on equipment failures and reliability.

These reports are normally filled out and signed by the person diagnosing the trouble or effecting the repair of the defective material. For defective airborne electronic material, one copy of the report is forwarded by the reporting activity, within seven days of the date of failure, to the Chief of the Bureau of Aeronautics.

A report must be submitted for each failure occurring, or upon determination that a part or tube is defective or unsatisfactory for any reason. In cases where two or more associated parts are found to be defective, and doubt exists as to which part is primarily at fault, each suspected part must be reported separately and reference made to all other reports of the associated failure. All reports of a multiple failure of the associated parts should then be fastened together to permit rapid evaluation.

Preparation of failure reports.—Form DD 787, shown in figure 5–1, is a check box type of report. The following items of information are required for each report in order that the maximum benefit may be realized from the system. (The item entries below correspond to the numbered areas of the report form.)

(1) Report number. Consecutive serial numbers are as-

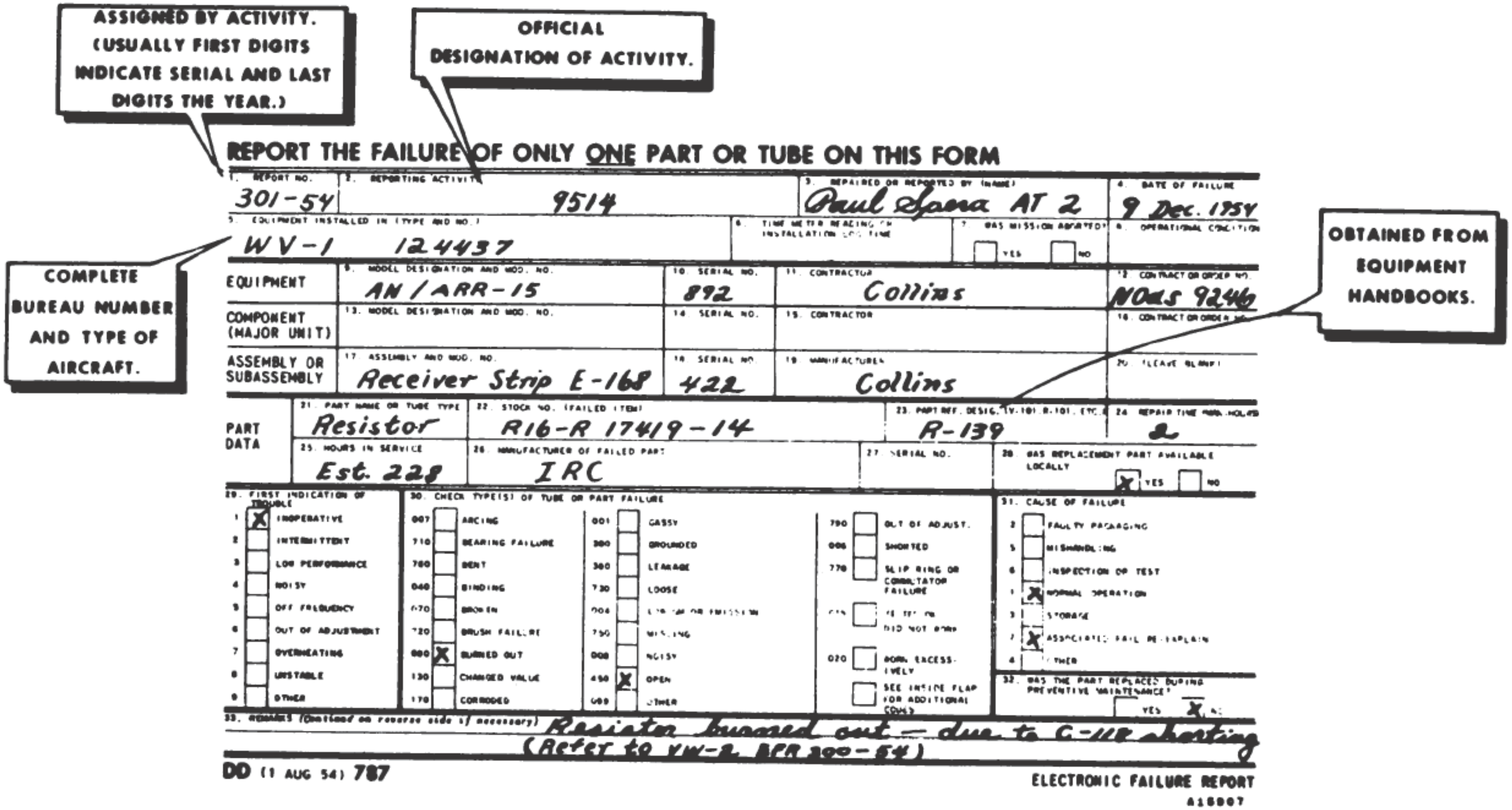


Figure 5-1.—Electronic Failure Report.

signed by the reporting activity. The entries consist of the report number and the last two digits of the year.

(2) Reporting activity. Normally the reporting activity is the custodian of the equipment at the time the fault or failure occurs, but may be the operating, service or other activity in which the equipment is operated or maintained. Instead of the customary activity designation (such as VW-2) the code designation of the reporting activity is entered in block (2). For example, 9514 is the code designation of VW-2.

In blocks (3), (4), and (5) are entered the signature of the technician affecting the repairs; the date of the failure; and the model and bureau number of the aircraft containing the defective equipment.

No entries are required by the Bureau of Aeronautics in blocks (6), (7), and (8). Blocks (6) and (7) may be filled in if desired; block (8) is for use by the Air Force only.

(9) Model designation and modification number. This entry is completed only when the failure or fault concerns an entire equipment group or installation, or a self-contained unit. When failures are restricted to a component, assembly, or subassembly, then either (13) or (17) should be used and (9) should be left blank. Normally the modification number does not apply to aeronautical electronic equipment except for ordnance items. Unless the nameplate specifically indicates a modification number, use the complete equipment designation, such as AN/APS-33C or AN/ARC-27A.

(10) Serial number. Serial numbers for the various components of an equipment are not necessarily similar; therefore the entry in block (10) is completed only for self-contained equipments. For failures of a component, assembly, or subassembly, use item (14) or item (18), whichever is appropriate.

Insert the contractor's name or code letters in block (11) as given on the nameplate. In cases where there may be more than one contractor code on the nameplate, indicate all codes in the entry. In cases where a component only is at fault, use the contractor's name or code from the component nameplate and insert the information in space (15).

When the fault or failure is traced to a subassembly, use space (19) to record the name or code of the manufacturer.

(12) (16) Contract or order number. Insert the contract or order number (which can be obtained from the nameplate of the equipment or component) in whichever of these blocks is appropriate.

(21) Part name or tube type. Insert the descriptive name of the failed part (for example, capacitor, resistor, tube 6AK5).

The stock number of the defective part can be obtained from a parts catalog or allowance list for the entry in block (22).

The part reference designator or symbol number (such as C–101, R–139) is obtained from the equipment handbook and entered in block (23). When reporting failures of mechanical parts, show the figure and index numbers pertaining to the part if these appear in the handbook.

(24) Repair time. Insert the actual time in man-hours expended in locating the trouble and in making the repairs in block (24). In cases of multiple failure, repair time should be prorated among the various parts replaced.

(25) Hours in service. Accurate record of equipment operation time may not be available. In this case, a reasonably accurate estimate of the equipment time should be made in block (25). This information is very important and every report should show an entry in this space.

(26) Manufacturer of failed part. If the defective part or tube contains a manufacturer's name or code, insert this data in block (26). If a serial number of the defective part or tube is available, the information is to be entered in item (27).

Indicate by a check mark in the appropriate space in block (28) if the replacement was available to the repair or service activity in shop stores or local supply.

Generally only one condition should be reported in block (29). Check one or more of the squares from the list of probable failures in item (30). Additional codings are affixed to each pad of DD 787 forms for use here if necessary.

The cause of failure is indicated by a check in the appro-

priate square of item (31). Indicate YES in item (32) if the fault or failure was discovered during routine scheduled inspection or check and if the fault was corrected without removing the equipment from the aircraft. If the defective item could not be repaired without removal from the aircraft or vehicle, check NO in item (32).

Use the space labeled "Remarks" (33), and the reverse of the form if necessary, for recording any additional data which may assist in an engineering evaluation of the reported condition. Generous use of this entry is encouraged.

ALLOWANCE LISTS AND TABLES OF BASIC ALLOWANCES

Bureau of Aeronautics Allowance Lists and Tables of Basic Allowances are lists of equipment and material determined from known or estimated requirements as necessary to place and maintain aeronautical activities in a condition of material readiness. These lists are approved and issued by direction of the Bureau of Aeronautics and should not be confused with stock catalogs or lists of material available in the regular supply system.

A complete listing of all Aeronautical Allowance Lists with NavAer publications numbers and effective dates is contained in the *NavAer Publications Index* and its revisions. These lists are divided into several sections with designating letters which further distinguish the material, aircraft, or material of the aircraft to which they pertain.

The portions of the allowance lists which concern the support, upkeep, and maintenance of electronic equipment and material are designated as Section "R" Allowance Lists. These lists are issued for specific squadrons, vessels, FASRons, units, or other activities engaged in the support and operation of aviation electronic equipment and material. In general, Section "R" Allowance Lists indicate allowances of electronic equipment, electronic test equipment, and material required by maintenance and operating activities for the support of installed aeronautical electronics equipment.

Additional lists of importance to the necessary mainte-

nance of electronic equipment as well as other accessory equipment of the aircraft are the Section "U" Allowance Lists. These lists include allowances of standard handtool kits which are available for use of aircraft maintenance activities.

Complete information concerning the use and application of the specific allowance lists is contained in the instructions to each list.

INSTRUCTIONS AND NOTICES

A system is in use throughout the Navy for the issuance of directive-type releases including those which prescribe policy, organization, methods, or procedures, and those which contain information. Certain publications, such as established manuals, operational releases, technical publications, some classified matter, and those joint Army-Navy-Air Force publications which are numbered serially, and not having separate Army or Air Force designations, are excluded from the system.

This program is called the Navy Directives System and provides a uniform plan for issuing and maintaining directives. Conformance to the system is required of all bureaus, offices, activities, and commands of the Navy. Two types of releases are authorized under the plan: Instructions and Notices.

INSTRUCTIONS are directives which contain information or require action of a continuing nature. An Instruction has permanent reference value and is effective until the originator supersedes or cancels it.

NOTICES are directives of a one-time nature and contain information or require action which can be completed immediately. A Notice does not have permanent reference value and contains provisions for its cancellation.

For reasons of identification and accurate filing, all directives can be recognized by the originator's authorized abbreviation, the type of release (whether an Instruction or Notice), a subject classification number; and in the case of Instructions only, a consecutive number. Because of their

temporary nature, the consecutive number is not assigned to Notices. This information is assigned by the originator and is placed on each page of the release.

The manner of numbering and identifying directives can be better understood by considering a typical identifier:

SECNAV	INST.	5215.1
(a)	(b)	(c) (d)

(a) Here the authorized abbreviation of the originator of the directive is placed.

(b) This part refers to the type of release, in this case an Instruction.

(c) This is the subject number which is determined by the subject matter of the directive and is obtained from the Table of Subject Classification Numbers.

(d) Following the period is the consecutive number which is found only on Instructions. An originator would assign consecutive numbers to those consecutive instructions with the same Subject Classification Number. In the example above the Subject Classification Number 5215 concerns "Issuance Systems." If the originator, SECNAV, issued additional Instructions dealing with issuance systems they would be assigned numbers 5215.2, 5215.3, 5215.4, etc. Subject classification numbers are listed in the Table of Subject Classification Numbers found in SECNAV Instruction 5215.1. This table contains a numerical and alphabetical listing of numbers with their related subjects, and is of considerable value for reference use when information or instructions of a particular nature are desired. This Instruction contains all necessary information concerning the use and procedures of the Navy Directive System.

QUIZ

1. The four handbooks prepared for each model of airborne electronics equipment are
   a. HOI, HSI, O/H, HOII
   b. HOI, HOII, HSI, IPB
   c. HOI, HSI, O/H, IPB
   d. HOI, HSI, HSII, IPB

2. Which of the following reports serves to provide up-to-date information concerning the reliability of electronic components?
   a. Tube Failure Reports
   b. Electronic Failure Reports
   c. Equipment Revision Reports
   d. Evaluation Reports

3. All changes to airborne equipment must be studied in detail to maintain a standard version throughout the fleet and must be authorized by
   a. BuShips
   b. BuDocks
   c. BuPers
   d. BuAer

4. The most valuable aid to the maintenance technician in maintaining the electronic equipment is the
   a. HOI
   b. HSI
   c. O/H
   d. IPB

5. The operator's handbook (HOI) for electronics equipment contains
   a. instructions necessary for adjustments, replacements, repairs, and recalibration
   b. a section on the theory of operation
   c. information on operating, disassembling, and reassembling
   d. very little technical information

6. A lubrication chart would be found in the
   a. *Standard Inventory Log* (SIL)
   b. *Handbook of Service Instructions* (HSI)
   c. *Handbook of Operating Instructions* (HOI)
   d. *Illustrated Parts Breakdown* (IPB)

7. To find information concerning maintenance of electronic equipment in the field you would use
   a. Section VIII of the HMI
   b. the overhaul handbook
   c. the *Handbook of Service Instructions*
   d. Section E of the *Standard Inventory Log*

8. Information on installation and removal of antennas would be found in the
   a. HOI for equipment
   b. HSI for equipment
   c. HOI for aircraft
   d. HSI for aircraft

9. The IPB is used primarily by
   a. maintenance men
   b. supply men
   c. overhaul and repair men
   d. pilots and operators
10. Revision to publications are
    a. listed in the alphabetical index section
    b. listed in the *NavAer Publications Index*
    c. sent to activities concerned each month
    d. listed in the table of contents section
11. The IPB is used by the technician mainly when
    a. ordering replacement parts
    b. tracing circuits
    c. sent to activities concerned each month
    d. listed in the table of contents section
12. In the general description of the theory of operation, as presented in the *Handbook of Service Instructions* the path of signal development can best be followed by using a
    a. wiring diagram
    b. schematic diagram
    c. block diagram
    d. voltage diagram
13. There are four types of diagrams used primarily for troubleshooting; they are
    a. schematic, wiring, voltage, and resistance
    b. schematic, wiring, block, and cabling
    c. schematic, wiring, voltage, and cabling
    d. schematic, wiring, voltage, and block
14. The most valuable diagram for theoretical troubleshooting is the
    a. wiring diagram
    b. schematic diagram
    c. voltage diagram
    d. resistance diagram
15. The most valuable diagram for location of parts in troubleshooting is the
    a. schematic diagram
    b. voltage diagram
    c. block diagram
    d. wiring diagram
16. Effects of relocation of equipment on aircraft must be analyzed primarily to prevent
    a. circuit load changes
    b. cabling changes
    c. weight and balance changes
    d. generator overload

17. Electronic Failure Reports should be filled out and signed by
    a. an Electronics Division Officer
    b. the technician diagnosing the trouble
    c. the supply officer
    d. the leading technician in the shop
18. In cases of failure of two or more parts in a single piece of equipment, the following procedure should be followed:
    a. A report must be submitted for each failure and all reports fastened together to permit rapid evaluation.
    b. A report must be submitted for each failure and sent in separately to avoid confusion.
    c. An overall report must be submitted including details to show relationship of parts to permit rapid evaluation.
    d. An overall report must be submitted excluding details of part relations to simplify study.
19. In the Navy Directives System,
    a. instructions are directives which are of a continuing nature and which remain effective until superseded or cancelled by originator
    b. instructions are directives of temporary nature and include a cancellation date
    c. instructions are directives of temporary nature and may be cancelled by commanding officer
    d. instructions are directives of continuing nature, cancelled by compliance
20. In the Navy Directives System,
    a. notices are directives of continuing nature from date of issue
    b. notices are directives of continuing nature and contain information which can be completed immediately
    c. notices are directives of one-time nature containing action which can be completed immediately and containing provisions for their cancellation
    d. notices are directives of one-time nature containing immediate action and permanent reference value
21. Instructions for use of the Navy Directives System are found in
    a. SECNAV Instruction 5215.1
    b. SECNAV Instruction Index Directory
    c. SECNAV Instruction 5211.5
    d. SECNAV Instruction Cross Index

CHAPTER 6

THE AN/APS-33 AIRCRAFT RADAR SET

This chapter and those which follow consist of descriptions of typical examples of airborne electronic equipment. The primary objectives of these chapters are to show the operational features of the examples chosen, the basic purposes for which they are used, the components which determine their capabilities, and the limitations under which they operate.

The present chapter is concerned with Radar Set AN/APS-33. This set exhibits many of the general principles and features discussed in chapter 2 of this book and in NavPers 10087, *Basic Electronics*, chapter 14. This system is a typical example of a very important class of aircraft radar electronic equipment.

Airborne radar sets such as AN/APS-33 are subject to certain operating conditions and limitations which are not found in other types of installations. The principal requirement in such equipment is the necessity for minimum weight. Each component must be designed so that it contributes the lowest possible amount to the total weight of the complete unit.

It is also necessary that aircraft sets have low power consumption since the electrical generating capacity in aircraft is limited. Furthermore, the equipment must operate efficiently under conditions of varying frequency.

Complete airborne radar installations are usually composed of many small parts instead of one or two large ones. This type of construction simplifies maintenance procedures,

makes installation easy, and allows ready removal of damaged components for repair. The physical layout of the components in the plane is such that the weight of the cables used to connect the various subassemblies is as low as possible.

Aircraft radar sets must be protected from the adverse effects of widely varying pressure and temperature. Very high voltage is employed in the equipment, and in the low atmospheric pressures encountered at high altitudes, the possibility of arc-over is increased. In the low temperatures of these altitudes, water vapor collected in the r-f components at low altitudes is very likely to condense. These difficulties are usually avoided by sealing the modulator and the receiver-transmitter units in pressure-tight containers and maintaining them under constant pressure at all altitudes.

Equipment of this type must function under conditions of severe shock and vibration. The components, as a result, are mounted on specially constructed shock-insulating mounts. Filtering and shielding of the set is highly important because of the presence in the plane of other electronic equipment such as communication receivers and transmitters; and precautions must be taken to prevent interference between the various electronic and electrical systems.

GENERAL DESCRIPTION AND OPERATIONAL FEATURES

Radar Set AN/APS–33 is designed to operate primarily as a search and navigation instrument with provision for beacon operation. Circuits and connections are also provided so that IFF (Identification Friend or Foe) and LAB (Low Altitude Bombing) equipment can be used. The set is intended for installation in larger aircraft such as patrol and bombing planes. It serves as a means of revealing the presence and location of surface vessels, aircraft, beacons, and other objects within the area covered in its operating range.

In the search function of the equipment, pulses of high peak power and very short duration are generated by the transmitter, and radiated in the form of a beam by a directional antenna. The beam is focused into a pattern a few degrees wide and shaped according to the cosecant-squared design. It is swept by movement of the antenna assembly either through 360 degrees or in a 60-degree sector. During the intervals between the transmitted pulses, the signals reflected from objects in the path of the beam are received by the same antenna used in transmitting and applied to a receiver. The antenna is switched alternately from transmitter to receiver by a duplexer.

Echo signals from targets are detected, amplified, and displayed on cathode-ray tube indicators, which are calibrated by range markers (circular lines which indicate the distance between the aircraft and the targets). The appearance of an indicator in normal and high-definition search is shown in figure 6–1.

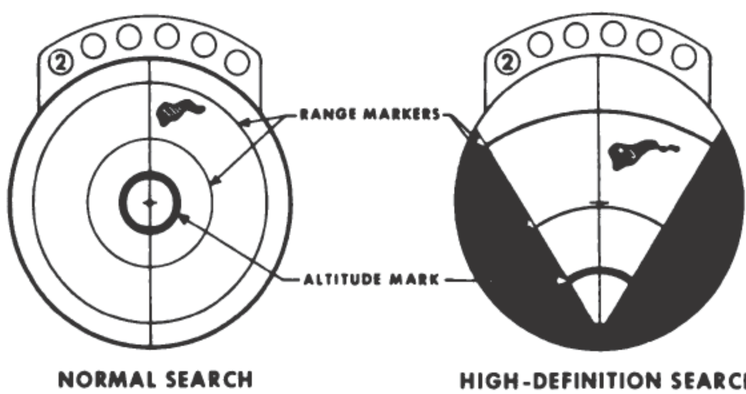


Figure 6–1.—Normal and high-definition search, AN/APS–33.

High-definition sector scan enables the operator to see a more detailed presentation of the area scanned by the radar. The narrow circles appearing on the screen are the range markers. The wide circle is the altitude mark which indicates the altitude of the plane above the earth's surface. At the top of the indicator face are six lights. One of the first five is illuminated to give the separation in miles between adjacent range markers. The sixth light, when

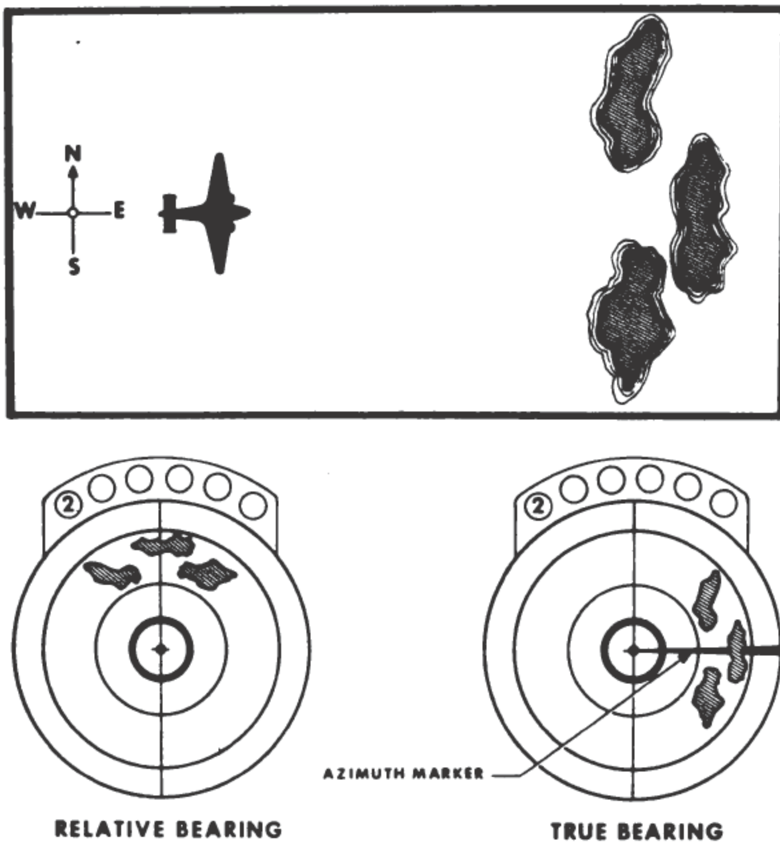


Figure 6–2.—Relative and true bearing indications.

illuminated, indicates that delayed-sweep operation is in use.

Radar Set AN/APS–33 provides both relative bearing and true bearing representation of targets. The two types of operation are shown in figure 6–2.

In relative bearing operation, the indicator presentation is viewed as though looking dead ahead from the cockpit. The scribed line on the indicator running through the top center of the display corresponds to the heading of the plane, and the targets are shown in relation to the course.

In true bearing operation, the display remains fixed regardless of the plane's heading, and the pattern is read like a map with the top center of the display indicating magnetic north.

The additional operational features of the AN/APS–33 include depressed sector scan, tilt stabilization of the antenna reflector, open center operation, altitude delay, and target discrimination operation.

The two types of sector scan presentation are shown in figure 6–3.

The use of sector scan results in better definition. The operator has a choice of two antenna scanning speeds. The depressed sector scan is employed in relative bearing operation, and has the advantage that a greater area of the screen is used.

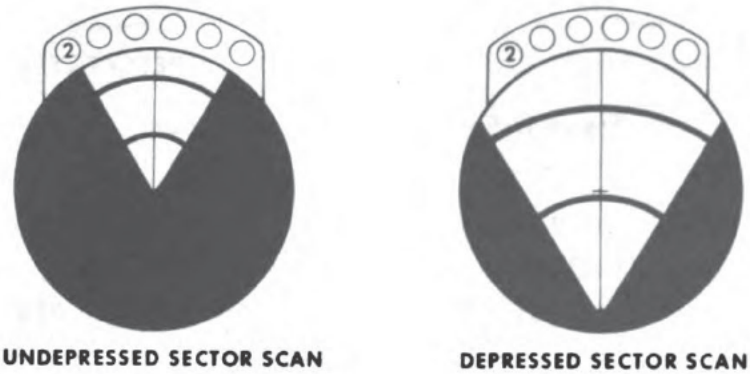


Figure 6–3.—Sector scan presentation.

Tilt stabilization is a process by which the tilt angle of the antenna reflector is held constant with respect to the true horizon at an angle selected by the operator regardless of changes in the attitude of the plane.

Tilt stabilization is especially valuable in maintaining targets on the indicator screen in rough weather. The general action of the stabilizing system is illustrated in figure 6–4.

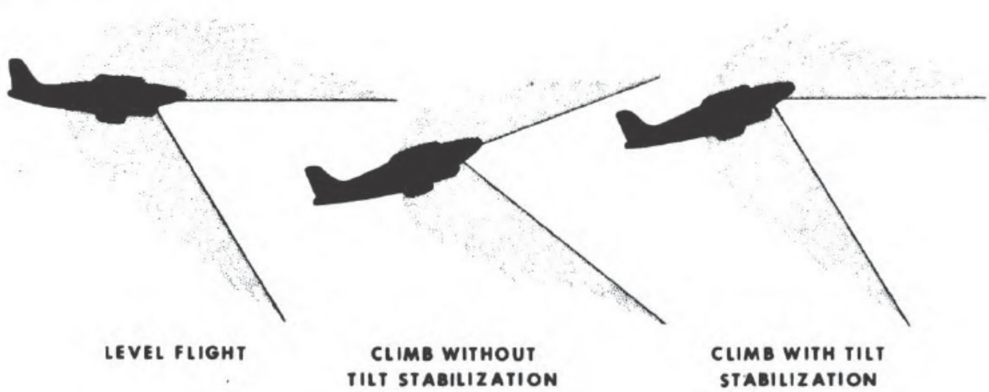


Figure 6–4.—Tilt stabilization.

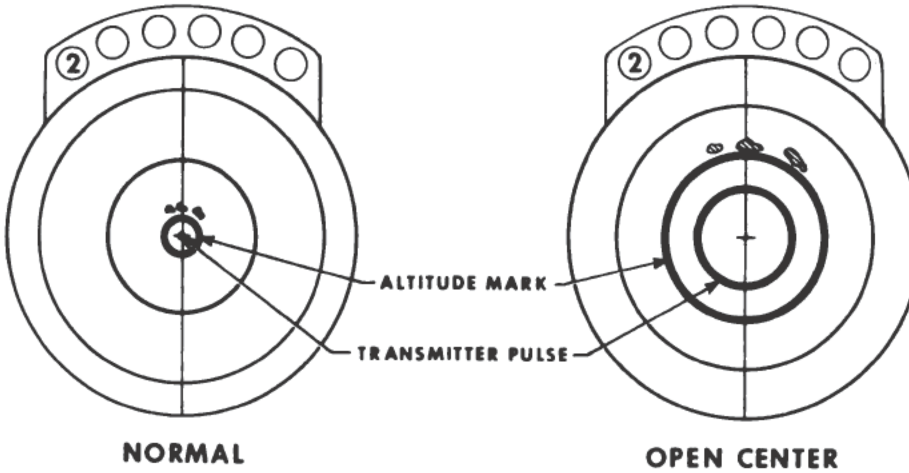


Figure 6–5.—Open center operation.

Open center operation, shown in figure 6–5, is used at short ranges to lessen the crowding of nearby targets. With this type of presentation, the images are spread out on the screen, allowing better identification of individual targets.

Altitude delay operation is provided for use at high altitudes to make available an otherwise wasted portion of the indicator screen. This type of operation gives a more realistic presentation of the area scanned.

In figure 6–6 in the normal screen presentation, an altitude of 5,000 feet is indicated by the wide, bright altitude mark near the start of the sweep. The portion of the screen

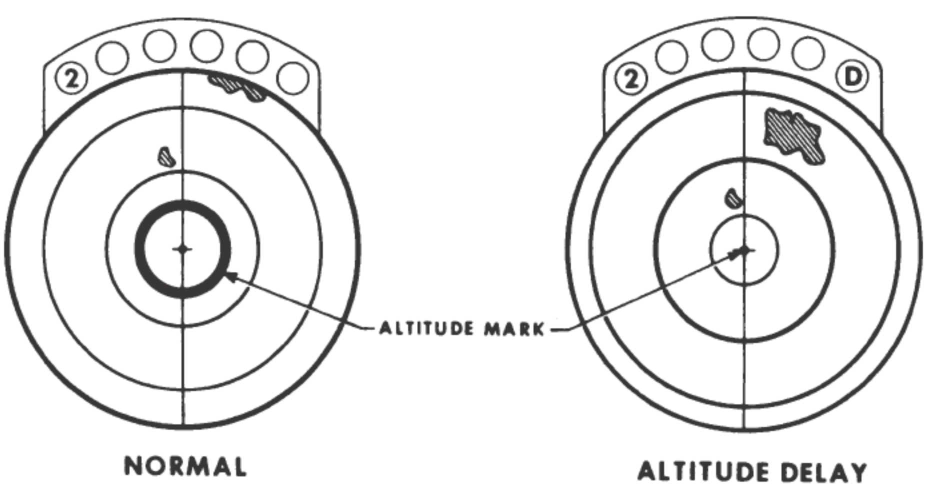


Figure 6–6.—Altitude delay operation.

below the altitude mark is wasted space. With altitude delay, the altitude mark is pulled down and coincides with the start of the sweep. The target which was only partially visible at the top of the screen has been moved down, making it completely visible.

Target discrimination operation, illustrated in figure 6–7 is used to provide an expanded view of a selected portion of the scanned area.

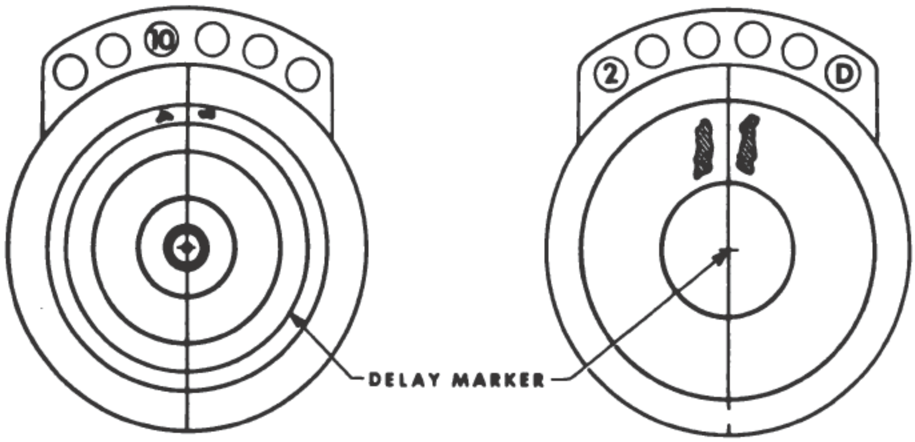


Figure 6–7.—Target discrimination operation.

With Radar Set AN/APS–33, any 5- or 30-nautical-mile portion of the presentation may be selected for expanded display. The circular delay marker line is moved by rotating the delay knob in the control unit to select the particular 5 or 30-nautical-mile portion of the screen area which the operator may wish to expand. In figure 6–7, the area between 26 and 31 nautical miles has been chosen for expansion to allow better identification of two distant targets. In the 5TD illustration in the figure, the entire screen represents the 5-nautical-mile area beyond the delay marker. This type of operation is accomplished by delaying and expanding the range sweep so that a ring-shaped area is collapsed into a small, solid circle.

During beacon operation of the set, pulses sent out by the

transmitter are received by a beacon station. The pulses trigger the beacon transmitter which radiates coded signals. These are received by the radar set and displayed on the indicator to reveal the location of the plane with respect to the known location of the beacon station.

MAJOR COMPONENTS

The principal components of the AN/APS–33 and their positions when installed in an airplane are shown in figure 6–8.

The components include an antenna assembly, a transmitter-receiver unit, a modulator, a synchronizer, two indicators, a true bearing amplifier, a gyroscope unit, a variable autotransformer, an inverter, a relay box, a junction box, two blower units, and a control unit.

The ANTENNA ASSEMBLY is mounted in conjunction with the TRANSMITTER-RECEIVER UNIT. The two are connected by a short length of waveguide containing a directional coupler. The antenna assembly also contains a servo amplifier and a pressurizing unit. The transmitter-receiver and the waveguide system are enclosed and operated under pressure controlled by the pressurizing unit.

The MODULATOR contains 28 tubes and provides the power pulses which control the action of the transmitter magnetron. In addition, the modulator supplies various d-c voltages, both regulated and unregulated, to the SYNCHRONIZER, the indicators, the transmitter-receiver, and the antenna assembly.

Two INDICATORS are included. Each contains four tubes in addition to the cathode-ray tube on which the radar presentation is made.

The TRUE BEARING AMPLIFIER is a part of the azimuth stabilization system. This system regulates the indicator display so that the top center of the presentation represents magnetic north in true bearing operation, and the display conforms to the customary map pattern. The amplifier contains two tubes, a zero-set synchro, two operating fuses, and a spare fuse.

The VARIABLE AUTOTRANSFORMER is used to control the

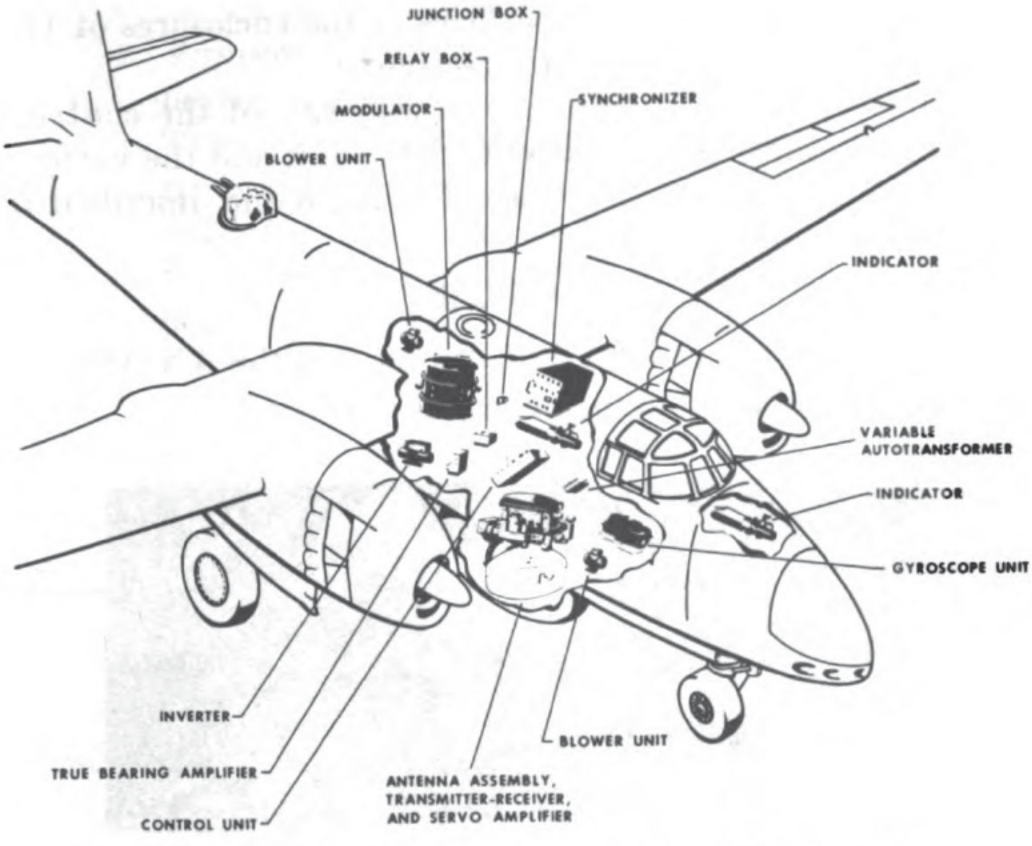


Figure 6–8.—Radar Set AN/APS–33, generalized installation.

a-c input power to the high-voltage supply in the modulator. Variation of the control knob on the autotransformer results in variation in the magnetron current which is indicated on the meter of the main control unit.

The GYROSCOPE UNIT is a part of the tilt stabilization system by means of which the antenna reflector is maintained at a preset angle with respect to the horizontal plane.

The INVERTER supplies 115-volt, three-phase, a-c power for the tilt stabilization and the tilt control system which positions and stabilizes the antenna reflector. A rectangular box mounted on top of the machine contains noise filter circuits and a carbon pile voltage regulator.

The RELAY BOX controls the starting of the inverter. It contains a starting relay, a thermal overload circuit breaker, and two protective fuses. The JUNCTION BOX connects the sweep voltage output from a synchro on the antenna assembly to both indicators. The two BLOWERS

circulate air over the outer surfaces of the enclosures of the modulator and the transmitter-receiver.

The CONTROL UNIT contains the majority of the controls used in operating the equipment. This unit and the various switches and dials it contains are illustrated and described in the following section.

Control Unit

The control unit, C–289/APS–31, used in the AN/APS–33 equipment is illustrated in figure 6–9.

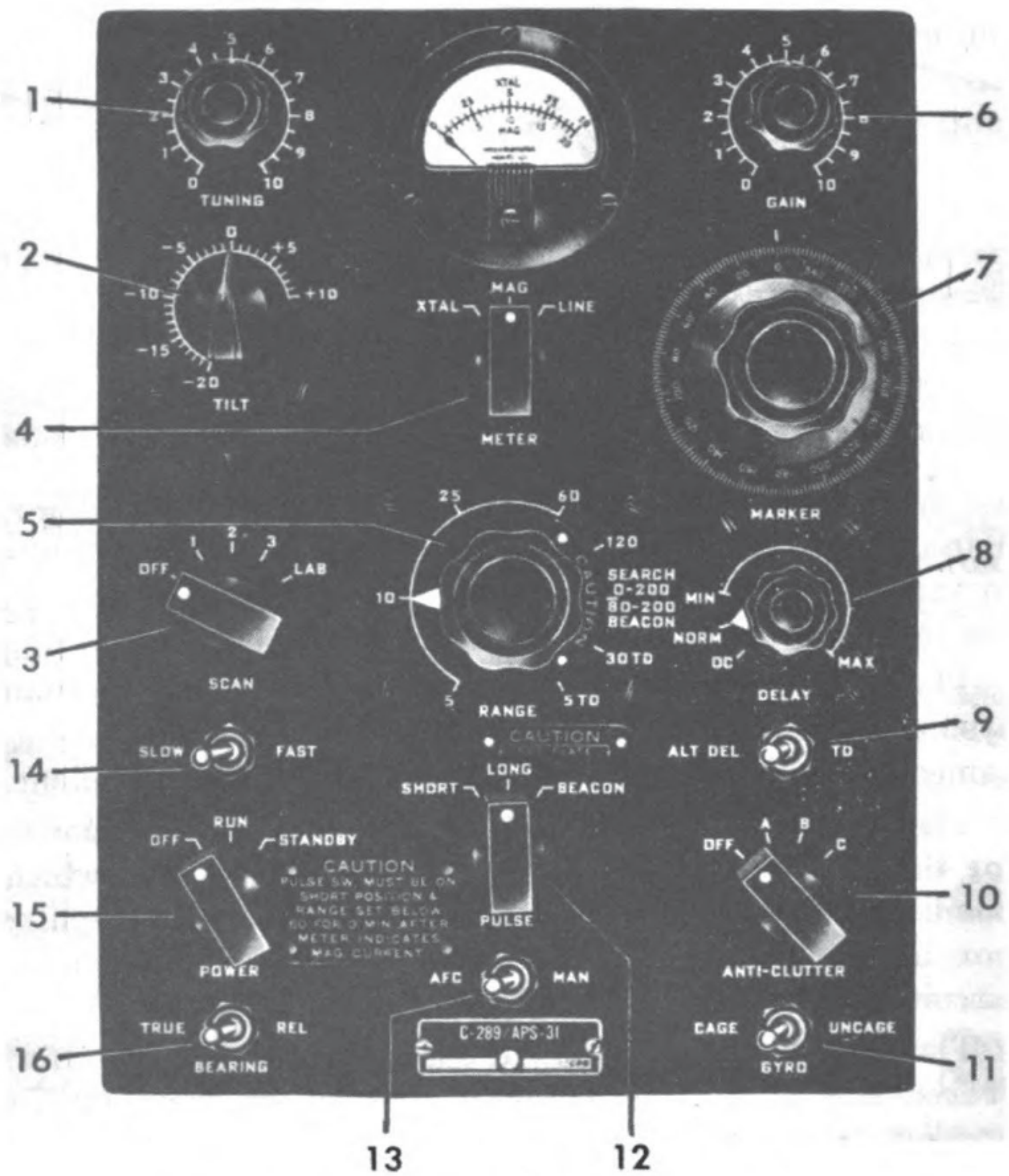


Figure 6–9.—Control unit C–289/APS–31 of Radar Set AN/APS–33.

The functions of the controls are as follows:

1. TUNING: Tunes the receiver for both search and beacon operation.
2. TILT: Controls the vertical tilt angle of the antenna reflector and adjusts this angle to the value indicated on the dial setting.
3. SCAN: Controls antenna rotation. In the OFF position, the antenna remains stationary. Positions 1 and 2 provide sector scan (depressed and undepressed, respectively). In position 3 the antenna operation is 360-degree rotation. In LAB position, sector scan is employed and the antenna is controlled by the associated low-altitude bombing equipment.
4. METER: The meter switch selects the proper meter range for measuring crystal current, magnetron current, or line voltage.
5. RANGE: The switch selects the desired operating range. The range is continuously variable from 5 to 60 nautical miles in search or beacon operation in accordance with the position to which the control is set. In the 120 position, the range is fixed at 0 to 120 nautical miles. In SEARCH 0–200 position, the range is fixed at 0 to 200 nautical miles. In 80–200 BEACON position, the range is fixed at 80 to 200 nautical miles. In the 30TD position, a 30-nautical-mile section of the area scanned is presented as an enlarged view. In the 5TD position, a 5-nautical-mile area is presented as an enlarged view.
6. GAIN: This dial controls the receiver gain.
7. MARKER: The marker dial sets the position of the azimuth marker on the indicator allowing the bearing of a target to be determined. In sector scan operation, the dial sets the direction of the midpoint of the 60-degree sector being scanned.
8. DELAY: In OC position, 1.5-nautical-mile open center operation is provided so that nearby targets may be more easily identified. No delay is pro-

vided in the NORM position. The MIN to MAX position provides continuously variable delay from 0–5 or 0–200 nautical miles, depending on the position of the switch just below the delay knob.

9. Alt Del–TD: The switch setting determines whether the range of the delay knob is 0–5 or 0–200 nautical miles.
10. Anticlutter: This switch controls the anticlutter circuits which assist in identifying targets in the presence of interfering signals.
11. Gyro: The switch position determines whether the gyro is held in a fixed position (CAGE) or is used in the tilt stabilization system (UNCAGED).
12. Pulse: By means of the three positions of the switch, short pulses for high-definition search operation, long pulses for normal search operation, or beacon pulses can be selected.
13. Afc-Man: This controls the receiver tuning permitting either automatic-frequency control or manual tuning control to be selected.
14. Slow-Fast: Governs the speed of rotation of the antenna reflector.
15. Power: The power switch disconnects all power from the equipment in the OFF position, applies power to the entire equipment in the RUN position (the transmitter high-voltage is applied automatically after the switch has been in RUN for three minutes), or applies all voltages except the transmitter high-voltage in STANDBY.
16. Bearing: In the TRUE position, the screen presentation is fixed with magnetic north appearing at the top center of the indicator. In the REL position, the top center of the screen represents the aircraft's heading and targets appear on the screen in positions relative to the course of the aircraft.

GENERAL ELECTRICAL CHARACTERISTICS

The AN/APS–33 equipment requires both a-c and d-c primary power. About 9 amperes of alternating current

are drawn at 115 volts. The a-c units are designed to operate over a frequency range of 380 to 1,600 cycles per second. The d-c requirements are 40 amperes at 27.5 volts.

The transmitter carrier frequency is 9,375 megacycles (plus-or-minus 55 mc.). In search operation, the receiver frequency is the same as the transmitter frequency; in beacon operation, the reception frequency is 9,310 megacycles. The receiver local oscillator operates 60 mc. below the transmitter frequency in search operations and 60 mc. below the frequency of the incoming signal in beacon operation.

The minimum r-f output power of the transmitter for acceptable operation is 52 kilowatts. Three pulse duration values are supplied by the modulator unit, MD–60A/APS–31, as follows:

Short pulse: 0.5 microseconds.

Beacon pulse: 2.25 microseconds.

Long pulse: 4.5 microseconds.

The values of the pulse repetition frequency are: 800 pulses per second with short pulse operation, 400 p. p. s. with beacon pulse, and 200 p. p. s. with long pulse operation.

The antenna assembly contains a feed horn type of radiator and a parabolic reflector. The beam width is between 2.4 and 3.6 degrees at the half-power points, depending on the antenna unit used. In vertical coverage, the radiated energy exhibits the cosecant-squared pattern.

The antenna scans 360 degrees for conventioanl PPI operation and 60 degrees (plus-or-minus 10 degrees) in sector scan.

Two antenna scanning speeds are provided: Fast scan is about 24 r. p. m. in 360-degree rotation and 90 to 100 looks per minute in sector scan; the slow scan rate is 8 r. p. m. and 40 to 50 looks per minute in sector scan. The antenna reflector may be tilted upward or downward with respect to a plane approximately horizontal by means of a manually controlled knob on the control unit. The gyro stabilizer maintains the preset angle even when the attitude of the aircraft varies from the horizontal by as much

as 30 degrees, either upward or downward, when the manual-tilt control is set at 0-degree.

THEORY OF OPERATION

The basic operation of the AN/APS–33 radar set involves the development of superhigh-frequency signals to be transmitted, the radiation of these signals from the antenna system, reception of the energy reflected from target-objects, and the presentation of the received signals on the indicators. The pattern on the indicator screen is then interpreted to reveal the range and azimuth of the targets. The major components which are used in these actions are shown in simplified functional block diagram form in figure 6–10.

Development of the transmitted signals.—The synchronizer contains a circuit, the master-trigger multivibrator, which generates a continuous series of pulses used for timing the entire equipment. In this circuit, pulses at the rate of 200, 400, or 800 per second, depending on the range and the operating function chosen, are fed to the fixed-delay circuit.

The fixed-delay circuit allows the firing of the transmitter to be delayed until after the start of the indicator sweep. Two time delays are provided: a short delay for normal operation which starts the outgoing pulse after the nonlinear portion of the sweep voltage has passed, and a longer delay for open center operation. (Open center presentation causes nearby targets to be displayed farther out on the indicator screen as shown in fig. 6–5.)

After leaving the fixed-delay circuit, the timing pulse is amplified and shaped in the trigger-shaper circuit of the modulator into a positive pulse somewhat rectangular in form. This pulse is applied to the grid of a thyratron tube through a cathode follower circuit. The thyratron acts as a switch to discharge the pulse-forming network, a combination of inductors and capacitors. The network is charged in the interval between pulses, from the high-voltage power supply in the modulator. The abrupt

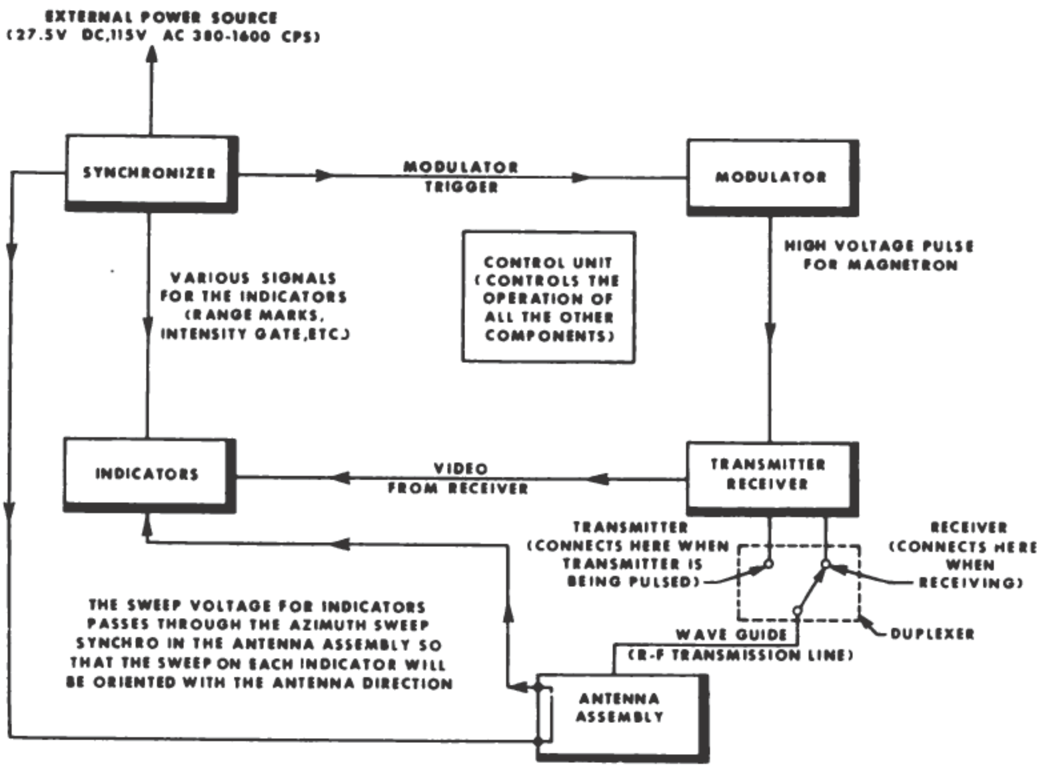


Figure 6–10.—Simplified functional block diagram, AN/APS–33.

discharge of the pulse-forming network gives rise to a high-amplitude pulse with a precisely controlled time duration. A cable connects the pulse to the receiver-transmitter where it is passed through a transformer and stepped up to approximately 15,000 volts before it is used to fire the transmitter magnetron.

The magnetron oscillates for the duration of the modulator pulse, sending superhigh-frequency energy at high power through the waveguide to the antenna. On the way, the transmitted pulse actuates the duplexer which acts as a switching arrangement to attach the transmitter to the antenna during transmission and to apply the reflected target signals to the receiver during reception. The switching components of the duplexer are the TR and ATR tubes.

The TR tube is located in the waveguide system at a point one-quarter wavelength from the path of the transmitted pulse. Ionized by the outgoing pulse, the TR box effectively short circuits the input to the receiver and places a

high impedance one-quarter wavelength away in parallel with the waveguide so that no shorting of the main pulse occurs. The ATR tube fires at the same time and has the effect of making the main waveguide wall continuous so that the pulse emerges with little loss.

Radiation system operation.—The superhigh-frequency energy is conducted through the directional coupler to the horn radiator in the antenna assembly and then into a reflector which releases a narrow beam into space. In the vertical plane, the beam is somewhat fan shaped, having the cosecant-squared pattern; and in the horizontal plane, the beam is from 2.4 to 3.6 degrees wide (depending on the antenna assembly in use). The scanner (the radiator and reflector) is rotated either continuously in one direction or back and forth causing the radiated beam of energy either to sweep the area around the aircraft or to sweep a selected 60-degree sector. Continuous rotation of the scanner results in the map-like presentation of the PPI scan.

The operator can set the angle of the antenna scanner with respect to the horizontal plane and so adjust the radiated beam of energy to cover desired areas. The angle of the scanner is set by means of the manual tilt control on the control unit. The control setting governs the action of a system containing several synchro units and a servo amplifier which supplies signal voltage to the tilt-torque motor. This motor swings the scanner to the desired angle selected at the control unit.

Once the tilt angle has been selected, the tilt stabilization system maintains the scanner angle and compensates for pitch of the aircraft. The central part of the tilt stabilization system is a gyroscope which remains on a constant vertical axis when the plane pitches and rolls. Within the gyroscope unit are synchros which develop signals corresponding to the instantaneous attitude of the plane. These signals are applied to the system of synchros and the servo amplifier which governs the tilt motor so as to keep the scanner at the chosen angle.

A second type of stabilization, azimuth stabilization, is employed in which the display on the indicator is stabilized

instead of the antenna assembly. The use of azimuth stabilization permits true bearing operation, in which the top of the indicator represents magnetic north regardless of the heading of the plane. With azimuth stabilization, when the heading of the plane changes, signals from the master indicator of the aircraft's fluxgate compass are applied to a synchro in the antenna assembly. The synchro applies a signal to the true bearing amplifier. The output of the amplifier controls the operation of a motor which adjusts the stator of the azimuth sweep synchro. This synchro corrects the pattern on the indicator to compensate for changes in the aircraft heading to maintain the customary map pattern in which north is represented by the top of the display. When azimuth stabilization is not in use, the top center of the display corresponds to the heading of the aircraft. In this type of operation, a signal from a synchro (the zero-set synchro) is applied to the true bearing amplifier input instead of the fluxgate compass signal.

RECEPTION OF REFLECTED SIGNALS.—When the pulse radiated from the antenna system strikes an object, a portion of the energy is reflected. The antenna rotates very slowly in comparison to the speed of the beam, and some of the reflected energy is picked up by the reflector of the antenna system and directed through the horn radiator and the waveguide into the duplexer from which it is applied to the receiver.

During beacon operation, the signal received is not reflected from an object, but is transmitted from a beacon station transmitter which is triggered by the pulse radiated from the radar set.

During reception, the ATR tube in the duplexer prevents the energy received from being dissipated in the magnetron cavity and directs it into the receiver mixer chamber. The TR tube remains un-ionized, removing the short circuit from the input to the receiver. The incoming signals are mixed with the output of the receiver local oscillator to provide the i-f signals. After several steps of i-f amplification, the signals are applied to the second detector from which they emerge as video variations. These are further ampli-

fied after passing through a process of limiting and are then fed to the indicators.

Two local oscillators are employed in the receiver—one for search and one for beacon operation. The local oscillator tubes are 2K25 reflex klystrons. The cathodes of the tubes are grounded, and the resonant cavities are operated at 300 positive volts. The repeller voltage can be varied in negative potential between 100 and 200 volts; and by this means, the frequency of the local oscillators is adjusted. The adjustment can be made either manually or by use of the automatic frequency control system. When automatic frequency control is employed, the search local oscillator is held at 60 megacycles below the magnetron frequency during search operation, and the beacon local oscillator is held at 60 mc. below the frequency of the incoming signals in beacon operation. The anticlutter circuits in the receiver reduce interference from sea or ground echoes, from rain squalls, and from jamming signals; a "stretching" circuit is used during beacon operation to make the received signals more discernible.

PRESENTATION CONTROL CIRCUITS.—As indicated in the block diagram of figure 6–10, the indicators are supplied with various signals in addition to the video information. These include the sweep voltage, the range marker pulses, voltage for producing the azimuth marker, and the intensity gate which unblanks the cathode-ray tubes to allow signals to become visible on the screens. These voltages are generated in circuits contained in the synchronizer which also includes the circuits which produce the fixed and variable time delay intervals used in open center, target discrimination, and altitude delay operations.

The time base or sweep for the indicators is a radial luminous line whose length is proportional to time, and consequently to range. The sweep circuit and compensating gate circuit employ 21 tubes to develop voltages and currents of the proper waveforms to provide a linear time base, or sweep. The sweep circuit generates voltages which produce linearly rising currents in the indicator deflection coils. The compensating gate circuit produces rectangular waves

of voltage which are at all times equal in area to the areas under the corresponding sweep waveforms and opposite to them in polarity. The two waves are combined in the driving circuits for the cathode-ray tube deflection coils. The resultant waveform insures that the sweep is linear and also that it starts at the same point each time without the use of clamp tubes. Before reaching the deflection coils, the sweep signals are fed through the azimuth sweep synchro in the antenna assembly for synchronization with the rotation of the scanner.

The azimuth marker, a bright radial line on the screen, is produced by voltages generated by an oscillator in the synchronizer. The oscillator is triggered by a pulse which coincides with the null of a signal originating in the azimuth marker synchro on the antenna assembly. When the scanner passes a point selected by the setting of the marker dial on the control unit, the oscillator is triggered, and the azimuth marker appears on the screen. By use of the control dial, the marker may be made to intersect a target image and the relative bearing of the target can then be read directly from the control dial. In sector scan operation, the signals which control the marker oscillator are such that the marker always appears in the center of the sector being scanned.

Intensity gating is controlled by either the sweep gate circuit or the range marker control circuit. The intensity gate circuit contains a cathode follower and a diode clamp tube. During normal operation, when range markers start, a pulse from the range marker gating circuit operates the intensity gate which unblanks the indicator to allow the range markers and other signals to appear on the screen. During target discrimination operation, the intensity gate circuit is controlled by the circuit which controls the sweep.

A range marker generator in the synchronizer develops equispaced pips which, when applied to the indicators, mark off the screens in luminous arcs graduated in nautical miles. Depending upon the range in use and the type of operation, five different sets of range markers are automatically supplied to the indicators for range measurement in intervals of

2-, 5-, 10-, 20-, and 50-nautical miles. The range pips are developed in a modified Hartley circuit used as a gated oscillator which generates oscillations with periods corresponding to the distance between the range markers. A trigger voltage from the modulator trigger circuit in the synchronizer is applied to the range marker gating circuit to actuate a switch tube which allows the oscillator to operate. The control of the range marker oscillator by the modulator trigger pulse insures that the range marker circuit operates in synchronism with the firing of the transmitter.

MASTER-TRIGGER MULTIVIBRATOR.—In the various phases of operation just described, certain circuits and components are of special importance. Among these is the master-trigger circuit in the synchronizer. In this circuit the timing pulses are initiated which determine the pulse repetition frequency. The value of the PRF appropriate for the type of operation and the range selected is determined by the circuit constants in use in the multivibrator, which is shown together with the output tube, a cathode follower, in figure 6–11.

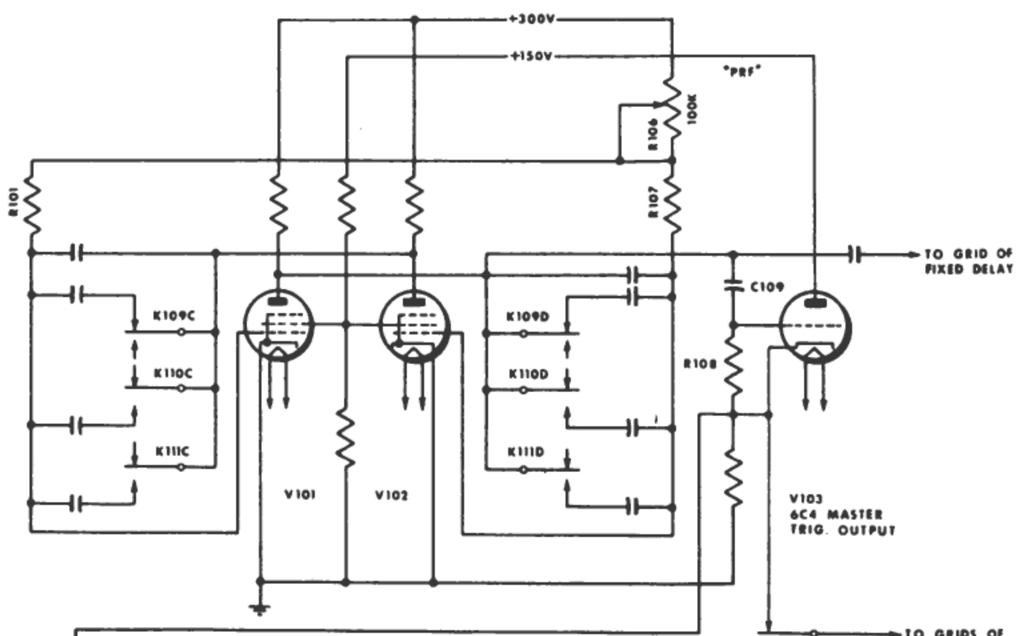


Figure 6–11.—Master-trigger multivibrator and output circuit.

Two 6AK5 pentodes, V101 and V102, are connected in a free-running multivibrator circuit. The screens are supplied through a voltage divider and no bias voltage is applied to the cathodes. The grids are returned to the positive supply voltage through large values of resistance (R101, R106, and R107).

The multivibrator generates waveforms somewhat rectangular in shape in the plate circuits. Assume that when plate voltage is applied, V102 produces a negative swing at the grid of V101. The decreasing plate current in V101 couples a positive swing to the grid of V102. This action proceeds until V102 is drawing maximum plate current and V101 is cut off. At this time, the R–C network in the grid of V101 which was charged by the foregoing action begins to discharge, and after a short time, allows plate current to resume in V101. This increasing current produces a negative swing at the grid of V102, which in turn applies a positive swing to the grid of V101; the action continues until V101 is conducting maximum plate current and V102 is cut off. As a result of the alternate periods of conduction and cutoff, the plate voltages of the tubes vary at a frequency determined by the time constants of the R–C circuits connected in the grid circuits. The values of the R–C circuits are changed by relay action to give the desired PRF.

A pulse repetition frequency of 1,600 pulses per second is selected when relay K109 is energized; when all the relays are in the de-energized condition, the 800 PRF results; the 400 PRF results when K110 is energized; and the 200 PRF is produced when K111 is energized. (The PRF of 1,600 was intended for high-definition search and is not used in AN/APS–33—the 800 value is used for normal search operation over medium ranges, and the 200 value for long ranges. The 400 PRF is used only for beacon operation.)

The variable resistor, R106, is a part of the R–C timing circuits which determine the action of the multivibrator. It is used as a fine adjustment of the pulse repetition frequency value.

The waveforms at the plate of V101 are coupled to the fixed-delay circuit and to an R–C combination consisting of

R108 and C109. The pulses fed to the fixed-delay system control the modulator and hence, the magnetron firing in normal and open center operation.

The signals applied through the R–C combination to the output tube, V103, control the timing of the circuits which govern the sweep currents in the indicator tubes. The combination, C109 and R108, is a differentiator circuit which produces peaked waves of voltage across the resistor when rectangular waves are applied. The peaked waves consist of positive and negative spikes of voltage, and these are attached between the grid and cathode of V103. The positive spikes have little effect on the action of the tube since it is already conducting heavily; but the negative spikes sharply reduce the cathode current and hence the cathode voltage. This action results in negative trigger pulses appearing at the cathode of the output tube.

The output pulses from V103 are applied to the variable delay circuit which contains a phantastron delay tube. In normal, or undelayed operation, these pulses are also applied through relay K114B to the circuit which controls the beginning of the sweep. In delayed operation, the sweep gate circuit is detached from the output tube and the starting of the sweep is controlled by the variable delay circuit.

THE MODULATOR.—The primary function of the modulator is to supply pulses of power to the magnetron tube in the transmitter-receiver. This is done by charging and discharging a pulse-forming network. The action of the modulator is controlled by trigger pulses originating in the synchronizer. These are shaped and amplified in the modulator and then applied to a thyratron switching tube which governs the action of the pulse network. The high-voltage pulse produced by the pulse network is then connected through a pulse transformer to the magnetron.

The principal operations of the modulator can be illustrated by the simplified schematic diagram shown in figure 6–12.

The pulse-forming network (shown considerably simplified) is composed of capacitors and air-core inductors connected to form an artificial transmission line containing four

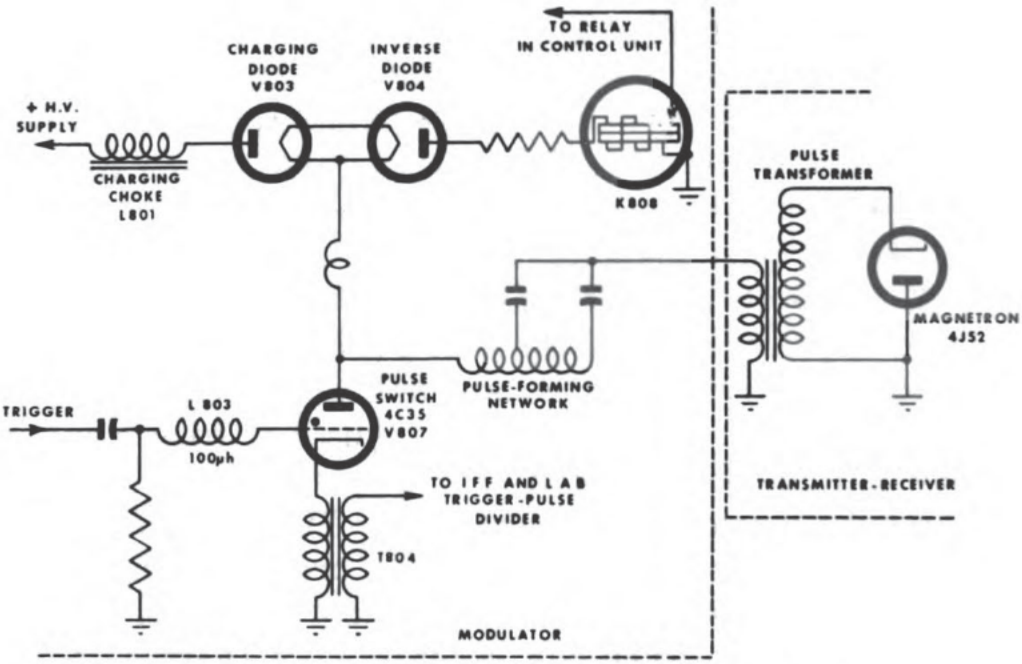


Figure 6–12.—Simplified modulator-pulse circuit.

sections. One or more of these sections can be selected to form the active portion of the network—the selection being made by relays which are governed by the settings of the control unit. The time constant of the active portion of the network determines the duration of the pulse developed and applied to the magnetron, and hence, the pulse duration of the radiated signal.

The pulse switching tube, V807, is a 4C35 triode thyratron which contains hydrogen gas. When this tube is nonconducting, the pulse network is applied to the high-voltage power supply through the charging diode. When V807 conducts, the network is discharged through the plate circuit of the switch tube and the primary of a pulse transformer in the transmitter-receiver. Conduction of V807 takes place when a positive trigger pulse is applied to the grid, causing the gas to ionize and plate current to flow. During discharge of the network, an approximately square pulse of negative voltage is applied to the cathode of the transmitter magnetron, causing it to oscillate and develop the superhigh-frequency energy to be transmitted. The duration of the modulator output pulse is determined by the time constant

of the active portion of the pulse network; the amplitude (about 15,000 volts) is determined by the potential to which the network is charged by the high-voltage power supply acting in series with the charging choke. When the voltage of the pulse network falls below the extinguishing voltage of the switch tube, plate current ceases, the discharge stops and the network is applied to the power supply to be recharged in preparation for the next pulse.

When the thyratron conducts, pulses are developed in the transformer T804. These voltages are used as trigger pulses for low-altitude bombing and IFF equipment.

The pulse network is charged by the high-voltage supply through the diode, V803. The diode provides a unidirectional charging path and serves to isolate the power supply from the network when the latter is fully charged. The large charging choke, L801, has several functions. It limits the peak charging current; it prevents excessive current being drawn from the power supply through V807; and it increases the voltage to which the pulse network is charged. The network voltage is increased because of self-induced voltage developed across L801 when the charging current begins to decrease. This voltage acts in series with the power supply potential to increase the voltage applied to the network. For example, with a power supply voltage of 4,700 volts, the network is charged to about 8,000 volts by the addition of the self-induced potential of the inductor.

The inverse diode, V804, and the thermal overload relay, K808, shown in figure 6–12, protect the modulator from overload and the magnetron from overheating when arcing occurs in the magnetron or in the waveguide system. Gas bursts or arcing cause the pulse-forming network to discharge through an impedance less than the characteristic impedance. This results in the reflected wavefront reversing the polarity of the charge across the line. If the reflected energy is not dissipated, the operation of the switching tube and the recharging of the network are interrupted, overload occurs, and the arcing condition is aggravated. The inverse diode conducts when the reflected pulses drive its cathode negative with respect to ground, and momentary reflections

are absorbed by the diode circuit. If the arcing persists, sufficient current flows through V804 and through the thermal relay to cause the contact points in K808 to open. This interrupts a control relay circuit with the result that the 115-volt, a-c power is removed from the input to the high-voltage supply in the modulator. (The filament voltage of the magnetron tube is also reset to the prestart value.) When relay K808 cools, contact is restored and the modulator power supply is again supplied with primary power. The momentary cooling period provided by the thermal relay usually corrects the condition which caused the excessive arcing in the magnetron.

THE DUPLEXER.—The duplexer which contains the TR and ATR tubes functions as an automatic switch, alternately transferring the waveguide from the receiver input to the transmitter as each pulse is sent out. The basic action of the duplexer in transmitting and receiving is indicated in figure 6–13.

The tubes are gas-filled resonant cavities which are coupled to the waveguide by glass-covered windows, or irises. When the transmitter is fired, the outgoing pulse causes the gas in the tubes to ionize and arc-discharge to take place in the cavities. In this condition, the ATR tube conducts the magnetron pulse in the main waveguide, and the TR tube excludes it from the input to the receiver. During reception, the weak echo signals do not cause ionization of the switching tubes; the ATR tube prevents the returned signals from being applied to the magnetron cavity and the TR tube allows signals to enter the receiver input.

The ATR cavity is mounted on the broad side of the waveguide and the TR box is coupled to the narrow side of the guide. This type of mounting causes the ATR to act as an equivalent series element and the TR to appear as a parallel equivalent element. The relation of these elements to the magnetron and the receiver can then be represented by the equivalent circuit shown in figure 6–14.

An outgoing pulse from the magnetron ionizes the gas in the ATR tube and in this condition the tube allows the power to flow toward the antenna with little loss. The TR tube

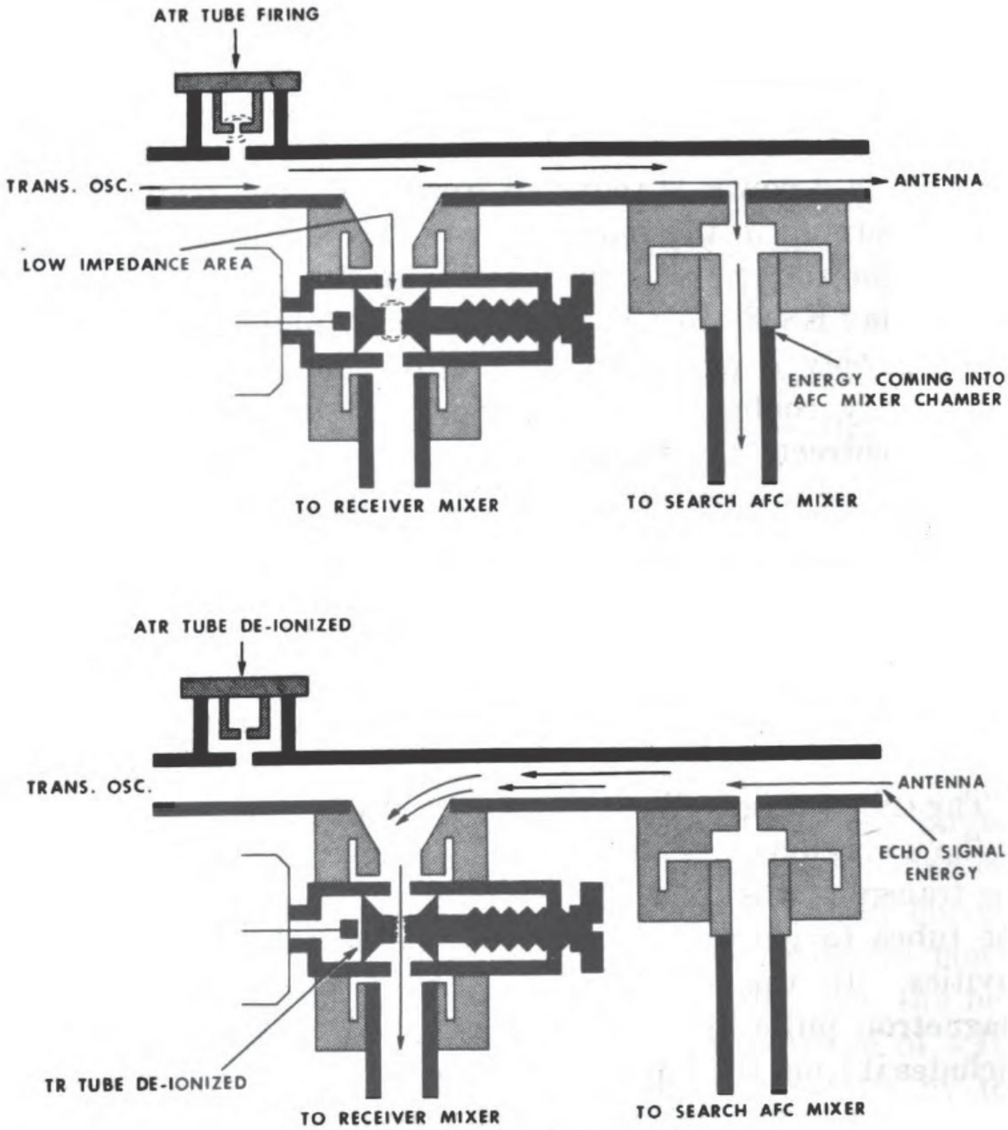


Figure 6–13.—Duplexer action.

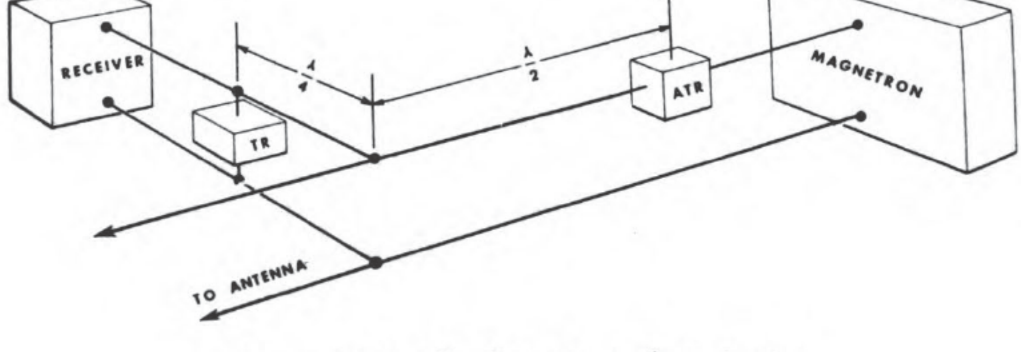


Figure 6–14.—Duplexer equivalent circuit.

in the line leading to the receiver also ionizes and short-circuits the receiver input, thereby protecting the delicate components in the receiver from burn-out. The equivalent section containing the TR tube resembles a quarter-wave parallel stub which is short-circuited by the arc-discharge. It places high impedance in shunt with the line and causes very little interference to the transmitted pulse while largely preventing the transmitter output from entering the receiver.

At the completion of the outgoing pulse, the breakdown in the tubes ceases and the system is ready to receive echo signals from targets. The impedance at the terminals leading into the magnetron is extremely high, since when un-ionized, the ATR tube is essentially an open circuit in series with the line with the open located one-half wave from the T-junction. In the direction of the receiver, the incoming signals see a matched line when the TR box is un-ionized, and the echo signals flow into the receiver input.

The ATR tube is a rectangular cavity closed at one end by a metal flange and at the other by the glass-covered coupling window. The opening at the lower face of the tube is placed over a hole in the waveguide so that the face of the tube is flush with the surface of the guide. The entire ATR tube is about one wavelength long and is mounted in a holder on the broad side of the guide. It is tuned at the factory by positioning a shorting partition inside the cavity to a point about one-quarter wavelength from the coupling window. The tuning adjustment is then sealed, making the tube a fixed-tuned element. During arc discharge, the breakdown occurs across the inner face of the glass window, causing the opening to appear as a continuous surface. In the un-ionized state, the cavity is equivalent to a shorted quarter-wave stub in series with the section of waveguide leading to the magnetron.

The TR tube, a 1B24, is a gas-filled resonant cavity containing two cone-shaped main electrodes and a keep-alive electrode. The latter is used to ionize the gas to a point just below breakdown so that a very small portion of the transmitted energy is needed to fire the gap between the main electrodes. The TR cavity is tuned to the frequency

of the search pulse; coupling into and out of the cavity is made by glass-covered resonant openings.

THE INDICATOR ASSEMBLY.—The indicator ID–162/APS–31 which is shown in simplified block diagram in figure 6–15 contains the cathode-ray indicator tube, the video amplifiers, a focusing coil, the deflection yokes, and the range marker lights.

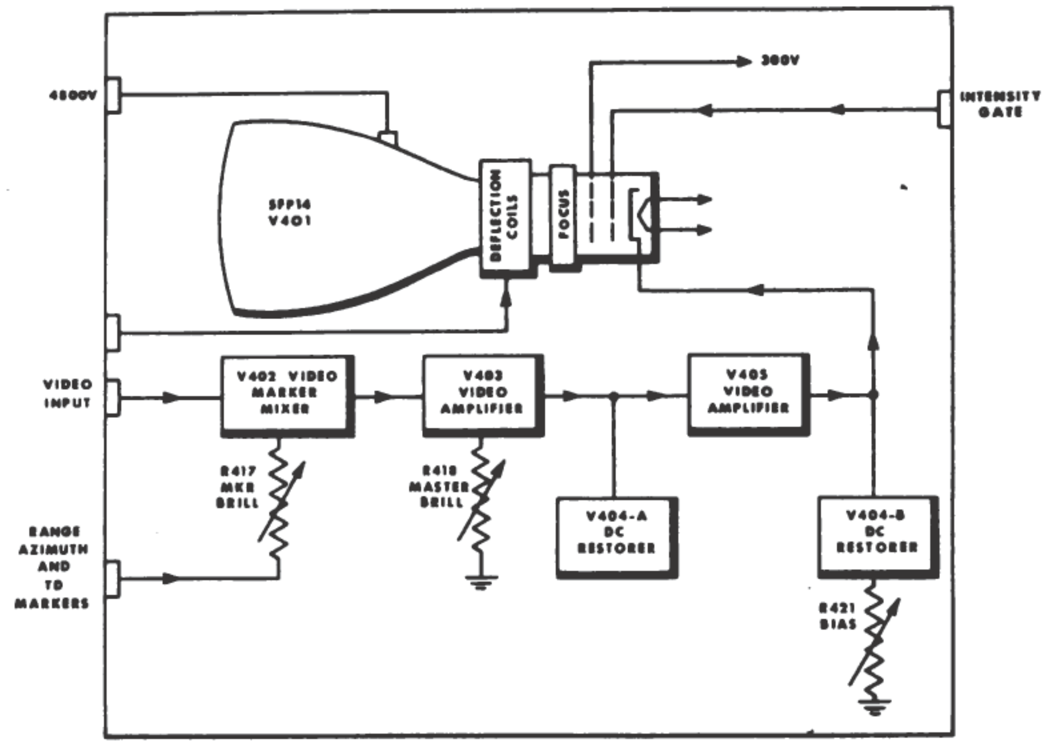


Figure 6–15.—Indicator block diagram.

The indicator tube on which the radar display is presented is a 5FP14 cathode-ray tube. Magnetic focusing of the electron beam is provided by means of a permanent magnet surrounding the neck of the tube. Focusing adjustments are made to regulate the sharpness of the sweep line appearing on the screen by use of a focus control mounted on the tube housing. The focus control varies the magnetic field of the permanent magnet by means of an adjustable armature.

Magnetic deflection of the electron beam is employed in the 5FP14 indicator tube. The deflection yoke to which the sweep signals are applied is attached electrically to the

stator windings of a two-phase synchro in the antenna assembly. The yoke surrounds the neck of the cathode-ray tube and has two a-c coils and two d-c coils. The a-c coils are wound 90 degrees out-of-phase and deflect the electron beam horizontally and vertically when supplied with voltage from the sweep synchro. The d-c coils are wound in the slots containing the a-c windings; one of the d-c coils produces vertical deflection of the beam to give depressed sector scan display on the indicator. The other d-c winding is called the roll coil and is provided for use with associated equipment but is not in use in Radar Sets AN/APS–33 and AN/APS–33A.

A positive potential of 4,800 volts is applied to the intensifier anode of the C–R tube from a supply in the modulator. The other indicator tube potentials originate either in the synchronizer or in the video circuits. The accelerating anode of the tube is operated at positive 300 volts, the control grid is at ground potential when the tube is unblanked, and the cathode is biased positive with respect to ground.

The video signals which produce the target or beacon images on the scope are applied to the indicator assembly from the receiver through a coaxial cable. As shown in figure 6–15, these signals are coupled to the video mixer (V402), a twin triode. One grid of V402 is supplied with range marker signals from the synchronizer. The input of the range marker section of the mixer contains a potentiometer, the marker brilliance control (R417) by means of which the brilliance of the markers visible on the indicator screen is regulated. The plates of both halves of the mixer sections contain a common load element, and the negative marker signals and the video voltages both appear in the output which is coupled to the grid of V403, a video amplifier. The cathode circuit of V403, a 6AK5 pentode, contains a variable resistor, R418, which is used as a master control for regulating the brilliance of both markers and the video target images on the scope screen.

The indicator tube cathode is given a positive bias by the connection to the potentiometer, R421. The d-c restorer, V404–B, conducts only when the video signals applied

attempt to drive the cathode more positive than the value of the bias voltage. As a result of the diode action, the cathode signals consist entirely of negative-going swings starting at the bias voltage level. These vary the intensity of the electron stream to produce the target images. Adjustment of the bias control determines the unblanking level of the indicator tube.

As indicated in figure 6–15, the intensity gate signal is applied to the control grid of the indicator tube. The unblanking gate is supplied by the synchronizer and is a pulse which swings from negative 40 volts to zero.

The final video stage, V405, is a 6AK5 pentode amplifier which applies amplified video and range marker signals to the cathode of the indicator tube. There, the voltage variations of the signal modulate the intensity of the electron beam during the intervals when the tube is unblanked and cause the visible images to appear on the screen. It is desirable that the signals applied to the cathode consist of negative-going variations which all start from the same potential, the zero-signal voltage. To provide this type of signal, two d-c restorer circuits are employed—one in the grid circuit of the video final stage, and the other in the cathode circuit of the indicator tube. The circuit arrangement of the output video stage and the d-c restorers is shown in figure 6–16.

The diode, V404–A, in parallel with a resistor connects the grid to a fixed negative potential of 4.5 volts. The diode conducts when the grid is driven more negative than this value. The diode does not conduct on positive swings of the control grid. Hence, the signals at the input of the final video amplifier consist only of positive-going variations, all of which start at 4.5 negative volts.

INTERMEDIATE-FREQUENCY AMPLIFIER SECTION.—In reception, the AN/APS–33 set employs nine stages of intermediate-frequency amplifiers followed by a video detector, a limiter, and a cathode follower output circuit. Associated with these in the conventional AN/APS–33 equipment are the anticlutter circuits which assist in bringing out target images in contrast to obscuring signals caused by echoes

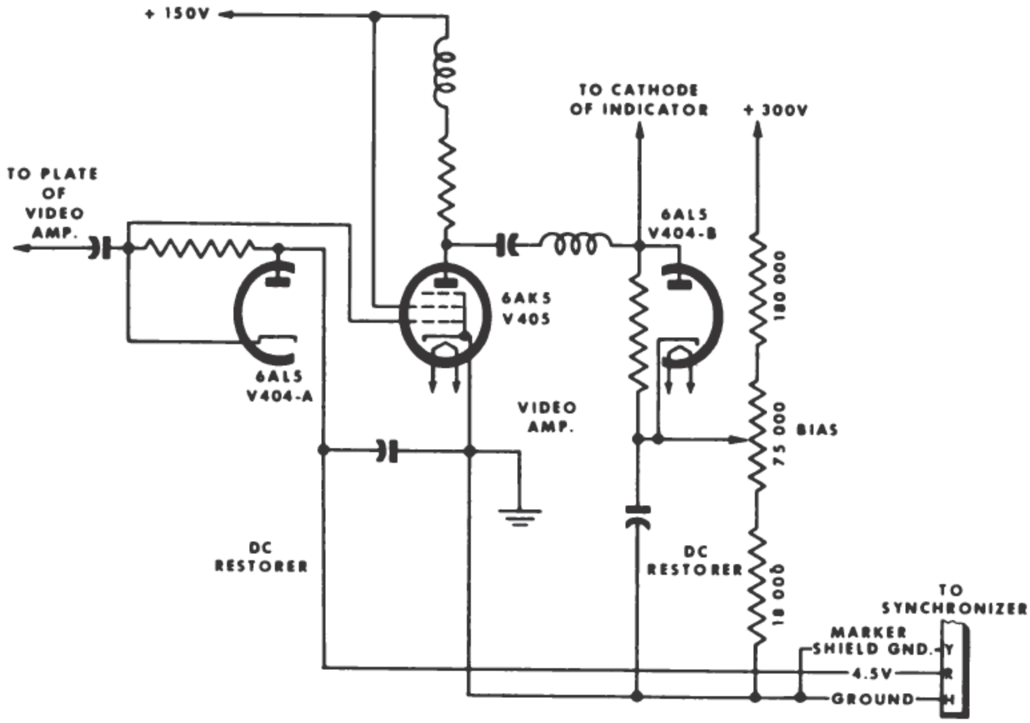


Figure 6–16.—Video output circuit of indicator.

from the sea or ground, from cloud formations and rain squalls, and from the presence of interference resulting from jamming.

Provision is made for replacing this section of the receiver-transmitter AN/APS–33 with a special type of receiver called a "lin-log" unit. When this replacement is made, a control unit associated with the lin-log equipment is also substituted for the conventional control box. In the lin-log receiver, no anticlutter circuits are used except a fast-time-constant R–C combination which can be switched into the input circuit of the video limiter. (The FTC circuit is a "differentiator" which prevents long blocks of signals from being coupled to the video tube.)

The lin-log i-f circuits can be operated either as linear or as logarithmic amplifiers. In linear operation, the output varies approximately as the amplitude of the input signal. With logarithmic operation, the output varies as the logarithm of the input signal. Furthermore, in linear operation, the video output signal appears first at the output terminals of the video detector; in logarithmic operation, the i-f

amplifiers serve as grid detectors for strong signals and the video output of these stages is the sum of all signals detected by the separate i-f stages.

The basic action in logarithmic response is the compression of strong signals. This type of operation of the i-f tubes is shown in figure 6–17.

If the signal voltage applied to the control grid of an amplifier tube is increased indefinitely, soon a voltage value is reached at which the grid begins to draw current. In this condition, the tube acts as a grid detector. Further increases in the signal voltage cause the amplifier to reach saturation. This principle is used in the logarithmic i-f action on strong signals. For very weak input signals, the tubes act as linear amplifiers with V–8 contributing a large part of the overall gain of the i-f section. If the signal voltage approaches the value E_1, shown on the graph, the grid of V–8 begins to draw current and the tube quickly saturates. Then no further gain is derived from this stage.

If the signal continues to increase, first V–7 and then V–6 begin to draw current in the grid circuits. As each saturates, the amount of gain it heretofore contributed to the output is removed—the larger the signal, the less is the overall amplification provided it. The video output consists of the grid current of V–8 for a moderately strong signal, the grid currents of V–8 and V–7 for medium strong signals, and of the grid currents of all three tubes on very strong signals. Thus, strong signals are compressed by the successive reduction in the number of tubes which contribute to the total gain as the signal strength increases. Weak signals do not cause the tubes to saturate and hence are amplified in each stage.

The logarithmic type of response is an aid in interpreting signals which might otherwise be lost. A linear receiver has a limited range of signal-handling capability, and the operator using it must "ride" the gain control when the target is changing rapidly in either aspect or range. If there is a weak target near a very strong one, it is virtually impossible to set the gain control so as to make both targets visible on the screen without the strong target either over-

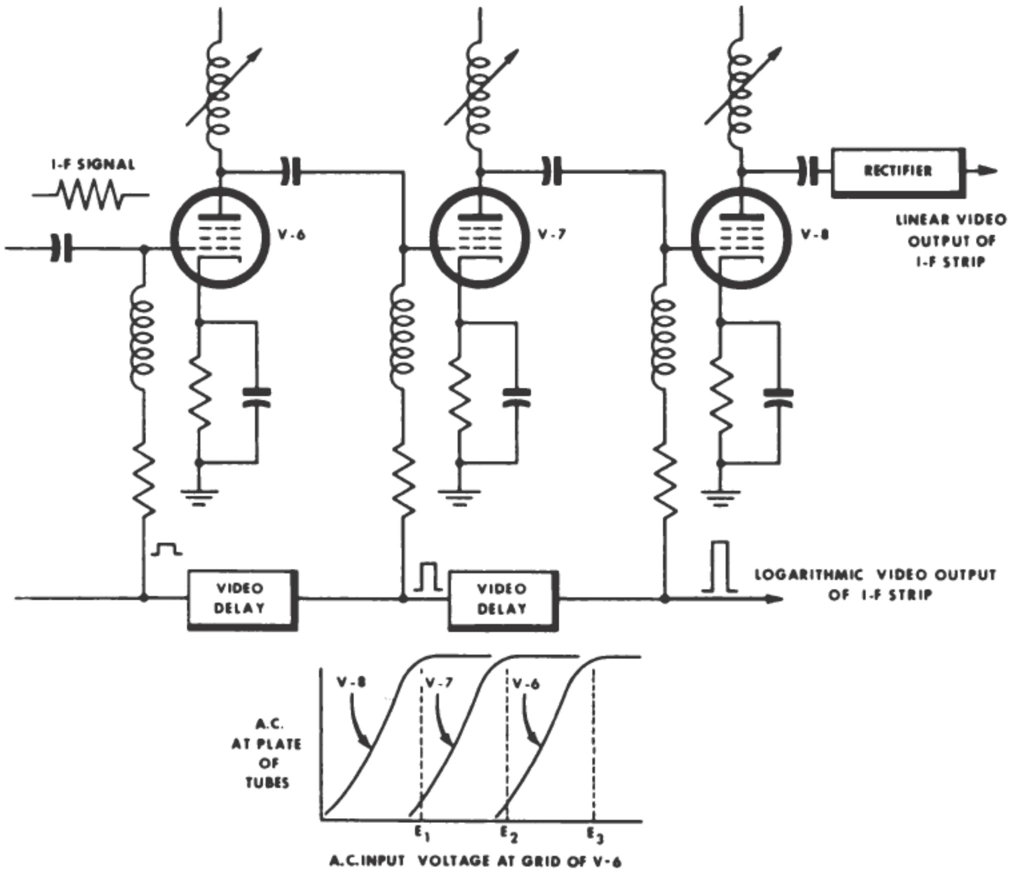


Figure 6-17.—Simplified lin-log i-f amplifiers.

loading the receiver or causing "blooming" on the scope. With the logarithmic response, the compression of strong targets is practically instantaneous, and a weak target adjacent to a strong target is clearly portrayed on the scope.

Another important feature of the logarithmic amplifier is that the receiver is always operating under a condition of maximum sensitivity. With the linear receiver, there is always the danger that the operator will decrease the receiver gain in order to study a nearby target and thereby miss a weak target at a greater range. With the lin-log receiver in logarithmic operation, the strong signal is automatically reduced in amplitude, but immediately following its termination, the receiver reverts to its condition of maximum sensitivity and is ready to detect any weak signals that are present.

The lin-log receiver unit can be used either as a linear receiver with a manual gain control or as a logarithmic receiver with a contrast control by changing the setting of the function switch on the control unit.

With this brief account of lin-log receiver action the present discussion of AN/APS–33 is concluded. Only a very few of the numerous circuits and details of the set have been mentioned: those which are most typical of airborne search radar and which play important parts in the basic operation of the equipment. For further information concerning the unit, the reader is referred to the *Handbook of Service Instructions* which contains schematic diagrams of all the circuits together with their theory of operation, many illustrations of the separate components, and authorized instructions for maintenance procedures.

QUIZ

1. In normal search operation of the AN/APS–33 the transmitter carrier output is
   a. low power and long pulse width
   b. high power and long pulse width
   c. low power and short pulse width
   d. high power and short pulse width
2. Open center operation is used in radar presentations to
   a. improve the discrimination of distant targets
   b. improve the discrimination of nearby targets
   c. increase the range of the radar
   d. decrease the range of the radar
3. When operating the AN/APS–33 on 30TD operation the operator sees
   a. a sweep that represents 0 to 30 miles of range
   b. any desired 30-mile section of the radar's range
   c. a sweep that is always delayed 30 miles
   d. the first 30 miles of sweep expanded and the rest of the sweep compressed

4. The high voltage pulse to the transmitter oscillator is furnished by the
   a. timer circuit
   b. duplexer system
   c. intensity gating circuit
   d. modulator

5. The AN/APS–33 magnetron current is controlled by varying the
   a. receiver tuning control
   b. receiver gain control
   c. variable autotransformer
   d. frequency of the a-c power input

6. Which of the statements below is true of the controls on the AN/APS–33 control box?
   a. The TUNING CONTROL tunes the receiver for both search and beacon.
   b. The METER SWITCH permits measuring of crystal current, magnetron current, and modulator current.
   c. RANGE MARKERS of 1, 5, or 20 miles appear as the range is varied from 0 to 60 miles.
   d. The MASTER CONTROL varies the width of the sector the antenna scans.

7. To trigger off or interrogate a radar beacon with the AN/APS–33, what transmitter pulse duration would be used?
   a. 0.25 microseconds
   b. 0.5 microseconds
   c. 2.25 microseconds
   d. 4.5 microseconds

8. For short range high-definition search the AN/APS–33 uses a pulse width of
   a. 0.5 microseconds and a pulse repetition frequency of 200 c. p. s.
   b. 4.5 microseconds and a pulse repetition frequency of 200 c. p. s.
   c. 0.5 microseconds and a pulse repetition frequency of 800 c. p. s.
   d. 4.5 microseconds and a pulse repetition frequency of 800 c. p. s.

9. The fixed-delay circuit in the AN/APS–33 synchronizer is used to delay the
   a. firing of the radar transmitter
   b. start of the sweep
   c. start of the range marker oscillator
   d. unblanking of the radar indicator

10. The pulse forming network of the AN/APS–33 modulator is a
    a. single-cycle blocking oscillator
    b. combination of inductors and capacitors
    c. R–C integrating circuit
    d. start-stop multivibrator

11. The beam of energy from the AN/APS–33 radar antenna has a
    a. wide horizontal beam width and a narrow vertical beam width
    b. narrow horizontal beam width and a wide vertical beam width
    c. cone of energy 3 degrees in diameter
    d. nondirectional coverage of 360 degrees

12. With tilt stabilization being used, if the plane changes attitude, the
    a. antenna beam will be positioned at zero degrees vertical angle with respect to the vertical plane
    b. antenna beam angle will stay positioned at the tilt control setting with respect to the horizontal plane
    c. antenna will sector scan a larger angle
    d. top of the scope will represent true north

13. To receive beacon signals on the AN/APS–33 radar as well as regular search targets
    a. two receiver i-f strips must be used
    b. two antennas must be used
    c. two local oscillators must be used
    d. two transmitter oscillators must be used

14. The receiver local oscillators in the AN/APS–33 are tuned by the automatic frequency control circuits by varying the local oscillators'
    a. shell voltage
    b. cathode voltage
    c. repeller plate voltage
    d. buncher grid voltage

15. The compensating gate circuits are used in the AN/APS–33 to
    a. compensate for minor changes in the sweep generator frequency
    b. increase the sweep amplitude on the indicator
    c. insure that each sweep starts at the same point on the scope
    d. obtain altitude delay for better scope presentation

16. The range marker circuit of the AN/APS–33 radar starts into operation with the
    a. start of the sweep
    b. firing of the transmitter
    c. unblanking of the scope
    d. application of the compensation voltage to the scope

17. The pulse repetition frequency of the AN/APS–33 is controlled by the
    a. modulator
    b. timer
    c. sweep generator
    d. range marker circuit

18. Referring to figure 6–12 of the AN/APS–33 modulator, one of the main functions of charging choke L801 is to
   a. give a higher charge on the pulse forming network than the supplied high voltage
   b. filter the d-c high voltage
   c. prevent current from flowing from the high voltage supply into the pulse forming network
   d. limit the voltage applied to the magnetron

19. The tube in the waveguide plumbing that ionizes when the transmitter fires and protects the receiver input circuit is the
   a. TR tube
   b. ATR tube
   c. klystron
   d. mixer crystal

20. Rapid ionization of the TR tube is obtained by the
   a. application of a keep-alive voltage
   b. introduction of water vapor into the tube
   c. application of a high filament voltage
   d. use of glass covered openings to the tube

21. Target pulses are applied to the AN/APS–33 indicator CRT by which of the following methods?
   a. Positive signals to the control grid
   b. Positive signals to the cathode
   c. Negative signals to the control grid
   d. Negative signals to the cathode

22. Unblanking is accomplished in the AN/APS–33 indicator CRT by applying a signal to the
   a. cathode
   b. control grid
   c. accelerating anode
   d. focusing anode

23. To limit the amplification of strong targets and to increase the amplification of weak targets the AN/APS–33 receiver uses a/an
   a. antijamming circuit
   b. logarithmic receiver
   c. linear receiver
   d. circuit known as a FTC (fast time constant)

24. An advantage of the logarithmic receiver is that it
   a. amplifies close targets to maximum
   b. is always operating at a desirable level of sensitivity
   c. reduces the amplification of close targets to a minimum
   d. does not use as many i-f amplifiers as the linear receiver

CHAPTER 7

INTRODUCTION TO AIRCRAFT COMMUNICATION EQUIPMENT

Aircraft communication equipment is used for the same general purpose for which shipboard and ground-based transmitters and receivers are employed. However, airborne units have certain characteristic features which result from the conditions under which they operate and which tend to distinguish them from other types of electronic installations.

In aircraft units, minimum weight and compact construction are considerations of primary importance. Airborne equipment must be light to avoid excessive reduction of the payload of the plane. Compact construction is required because the space available for radio installations in aircraft is usually limited. As a result of these limitations, airborne units are generally comparatively low in power rating since the designer is prevented from selecting the large, heavy components required in high-wattage installations. The need for compactness has made the transceiver a typical type of airborne unit. In this device transmitting and receiving circuits are contained in a single housing, and many of the circuits are shared by the transmitter and receiver sections.

Among the characteristic features of airborne radio equipment are the use of automatic tuning systems, the subassembly type of construction, shock mounting of the major components, provisions for minimizing arc-over of high-

potential leads when operating at high altitudes, and the use of dynamotors to supply high-voltage, d-c power.

Automatic tuning is desirable in airborne radio operation since the tuning adjustments must be made quickly and accurately. The automatic system provides for rapid selection of preset channels with great simplicity of control—usually the entire tuning operation in channel changing is accomplished by the use of a single dial.

The use of shock mounting results from the presence of physical shock and vibration as normal conditions in aircraft operations. The construction of the equipment in subassemblies simplifies maintenance and repair, allowing a section containing defective parts to be removed and replaced without dismantling the entire equipment.

The primary source of power for airborne communication equipment is usually an engine-driven generator which supplies d-c energy at about 28 volts. This voltage is generally converted into the high potentials needed in the plate and screen circuits of the electronic tubes by the use of a dynamotor.

These characteristic features are exhibited in the two typical examples of airborne communication equipment which are described in the following pages. One of these, the AN/ART–13, a radio transmitter, represents a comparatively early stage in the development of military aircraft radio communication systems. The other, the AN/ARC–27, is a transceiver which represents a latter period of development. The first of these is a transmitter which operates in the medium-frequency and high-frequency bands; the transceiver was designed for the ultrahigh-frequency portion of the radio spectrum.

In the following descriptions of these representative examples of communication sets, only the fundamental features are given. The circuits are represented largely by block diagram, and the emphasis is on the types and purposes of the stages on which the performance capabilities and limitations of the equipment are based.

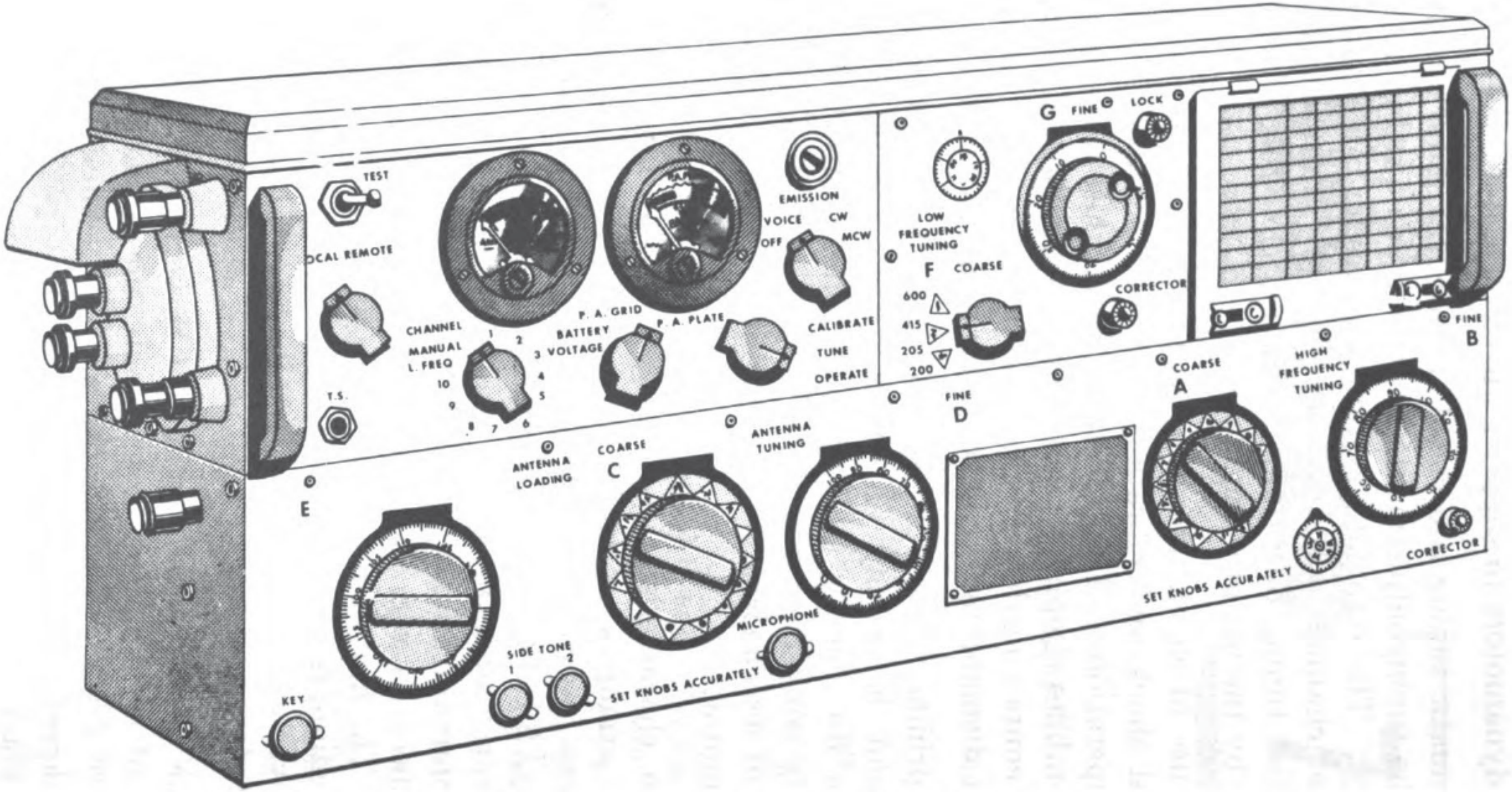


Figure 7-1.—Transmitter unit, T-47/ART-13.

MODEL AN/ART-13 AIRCRAFT RADIO EQUIPMENT

The AN/ART–13 radio equipment consists principally of a transmitter designed for installation in aircraft. The transmitter, which provides radio communication by means of CW, MCW, or VOICE types of emission, is shown in figure 7–1.

As in all typical airborne installations, care has been taken in the design of this transmitter to provide a mechanical construction that is capable of withstanding the severe vibration and shock which is present in normal airborne service. The materials used in the equipment are, as far as practicable, resistant to corrosion which often results from the chemical action of moist, salt-laden air. The subassembly type of construction is used in the transmitter; this allows removal of the component parts without the necessity of major disassembly.

Transmissions can be made on any one of eleven preset frequencies. Rapid changes in operating frequency are made possible by the use of an automatic tuning mechanism called the autotune system. With this system, variable tuning inductors, variable tuning capacitors, and switches are positioned automatically by mechanical means; the mechanical system is controlled electrically either from the transmitter panel, the pilot's control unit, or other remote control units. The accuracy with which the autotune system adjusts the frequency-setting elements is of a very high order, and the frequency adjustments are not affected by wear of the mechanical parts, by humidity, or by changes in temperature.

One of the eleven autotune positions can be used for low-frequency operation in the range from 200 to 1,500 kc. provided a low-frequency oscillator unit (O–16/ART–13) is installed in the transmitter and provided that external loading coils and a trailing wire antenna are used.

Electrical Characteristics

The transmitter shown in figure 7–1 is designed to operate with a 28-volt, d-c power source. Voltages as low as 24-volts may be used in emergency operation, but this results in lowered output power and in longer operating time for the autotune system, which normally requires less than 25 seconds for a complete cycle.

The d-c power source must be capable of supplying an average current of about 35 amperes and surge currents up to 50 amperes.

When operated at altitudes above 25,000 feet, a relay in the transmitter control circuit is activated by atmospheric pressure. The action of the relay reduces the plate voltage on the power amplifier and the modulator tubes to prevent arc-over. The reduction in plate voltage results in an output power of about one-half that produced with full voltage.

The primary power required for each type of operation is as follows:

Type of Emission	*Full Power*	*Half Power*
CW	770 watts	658 watts.
MCW	855 watts	700 watts.
VOICE (Unmodulated)	800 watts	672 watts.
VOICE (Modulated)	896 watts	700 watts.

High-voltage, d-c power is supplied by a dynamotor which produces two output potentials, 400 volts and 750 volts. These two are added to produce 1,150 volts for use in the power amplifier plate circuit and in the modulator plate circuit.

The output power derived from the transmitter varies with the frequency of operation and ranges from about 5.5 watts at 200 kc. to 90 watts at frequencies from 5.5 megacycles to 13.5 megacycles.

Two ranges of operating frequencies are provided. The low-frequency range extends from 200 kc. to 1,500 kc. The high-frequency range extends from 2 to 18.1 megacycles. The output falls off for the higher frequencies to approximately 6.5 watts at 18.1 mc.

Major Components of the AN/ART-13

The major components of the AN/ART–13 equipment consist of the transmitter (T–47/ART–13), a dynamotor (DY–12/ART–13), the pilot's control unit, and the antenna shunt capacitor (CU–24/ART–13).

The dynamotor supplies d-c voltages for the screen and plate circuits of the transmitter. It contains an armature equipped with dual windings and two commutators which provide two voltages, 400 and 750. These two values are combined to supply plate voltage for the power amplifier and the modulator tubes. The 400-volt output circuit of the dynamotor is protected from overload by a 1-ampere fuse. Two thermally operated, reset-type relays protect the 28-volt input circuit of the machine.

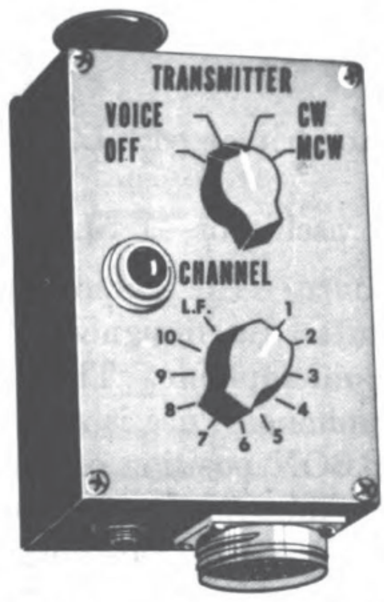


Figure 7–2.—Pilot's control unit.

The operating channel and the type of emission are selected and controlled at the transmitter panel, from remote control units, or from the pilot's control unit. One model of the pilot's control unit is illustrated in figure 7–2.

An antenna shunt capacitor is used when the equipment is operated in the 2,000 to 3,000 kc. range if the antenna in use does not have sufficient capacitance to permit tuning the output circuit to resonance.

Two loading coil units are available with the equipment and are used in the 200 to 500 kc. and the 500 to 1,500 kc. ranges.

Technical Summary

Tube complement.—Twelve tubes are used in the transmitter. The tube types and their distribution in the three sections of the transmitter are as follows:

Radio-frequency section:
- 1 H-f oscillator—837
- 2 Frequency multipliers—1625
- 1 Power amplifier—813

Audio-frequency section:
- 1 Audio amplifier—12SJ7
- 1 Audio driver—6V6GT
- 2 Modulators—811

Calibration system:
- 1 Crystal oscillator-tripler—12SL7GT
- 1 Mixer—12SA7
- 1 Detector-audio oscillator—12SL7GT

Microphone circuit.—The audio input circuit of the AN/ART–13 transmitter is designed to match either a carbon or a dynamic microphone. The proper input circuit for the type of microphone in use is selected by means of a switch. In the CARBON position of the switch, provision is made for matching a microphone of about 40 ohms internal resistance; in the DYNAMIC position, the input circuit matches a dynamic microphone of about 200 ohms internal resistance.

Modulation.—Class B modulation is used. The 811 modulators are operated in push-pull and are capable of supplying sufficient audio-frequency power to modulate the r-f carrier up to 90 percent when operating with voice emission.

The audio stages pass all audio signals between 200 cycles per second and 5,000 cycles per second within three decibels.

Power control circuit.—The primary power is controlled by contactors located in the dynamotor.

General Theory of Operation

The transmitter consists of three major sections: the radio-frequency section, the audio system and the crystal frequency indicator (calibration) section. The stages included in these sections are shown in block diagram form in figure 7–3.

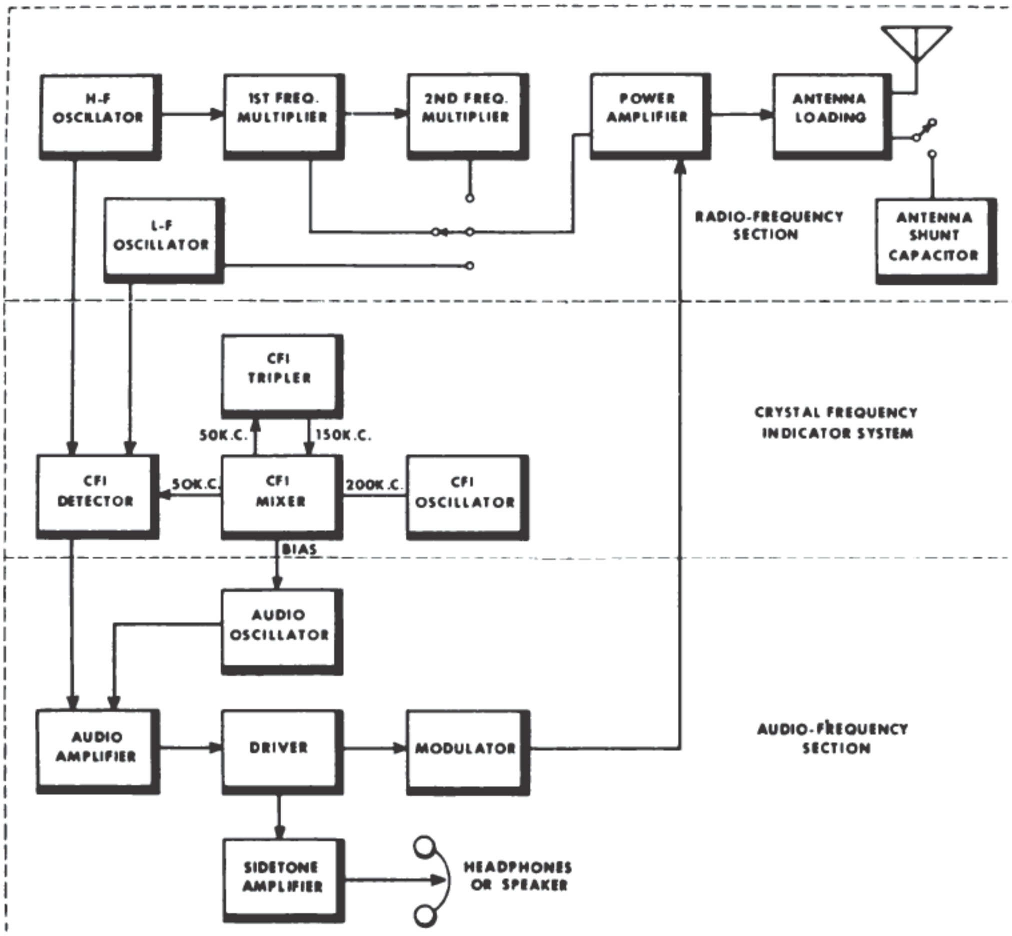


Figure 7–3.—Block diagram, T–47/ART–13.

RADIO-FREQUENCY SECTION.—The r-f signal is initiated in either a high-frequency or a low-frequency oscillator. The high-frequency oscillator is used when the transmitter is operated in the 2- to 18.1-mc. range. The low-frequency oscillator unit is employed during operation on frequencies between 200 and 1,500 kilocycles.

The high-frequency oscillator tube is an 837 pentode,

which is connected in an electron-coupled Colpitts circuit. The h-f oscillator generates signals in the frequency range from 1,000 to 1,510 kc. This range is covered in two bands, 1,000 to 1,200 kc. and 1,200 to 1,510 kc. The band in use is determined by the position of a switch which is operated by means of the coarse frequency tuning adjustment of the control panel. Fine frequency adjustments are made within each band by varying the setting of a fine frequency control knob which sets the inductance values in the oscillator tuning circuits.

In low-frequency operation of the transmitter, the output of the l-f oscillator is applied to the input of the final amplifier stage with no frequency multiplication. The l-f oscillator is a plug-in assembly using a 1625 pentode. When the equipment is operated in the high-frequency range, the output of the h-f oscillator is multiplied in frequency before amplification by the final power amplifier.

Two frequency multiplier stages containing type 1625 beam pentode tubes are used. The first multiplier may be operated as a frequency doubler, as a tripler, or as a quadrupler. The second multiplier functions only as a tripler. By means of the various combinations of multiplication thus provided, the output frequency of the oscillator can be increased from two to twelve times, giving a frequency range of 2 to 18.1 mc.

The amount of multiplication in effect is determined by the setting of the coarse frequency control knob (Control A) on the transmitter panel. Control A has 12 high-frequency positions. In the first six positions the output of the first multiplier is connected to the grid of the power amplifier tube and the second multiplier stage is inoperative. In the last six positions of the control knob, both multiplier stages are in operation. (Multiplier selection is symbolized in fig. 7–3 by means of a switch.)

Plate and screen voltages for the multiplier tubes are supplied by the 400-volt section of the dynamotor. The screen voltages are reduced to about 270 volts by series resistors.

The power amplifier stage contains a type 813 tube oper-

ated in class C. The final stage provides no frequency multiplication but operates as a straight through amplifier on all operating frequencies. Bias voltage in the power amplifier is developed by the action of grid current flowing in a grid-leak resistor. Screen voltage is supplied by the low-voltage section of the dynamotor. The plate voltage is 1,150 volts except when operating at high altitudes when the action of the pressure-operated relay causes the plate potential to be reduced to 750 volts. Grid and plate current in the power amplifier tube may be measured by means of a meter located on the transmitter panel. The meter is placed in the circuit to be measured by means of a selector switch.

The output of the power amplifier tube is capacitively coupled to the plate tuning circuit and to the antenna coupling, or loading, network. The coupling network is connected either as a pi or an L section, depending on the setting of a switch which governs the arrangement of the capacitors and inductors in the network. By means of these arrangements, the coupling circuit provides for matching the plate circuit impedance to the impedance of typical aircraft antennas when operating at frequencies from 3 to 18.1 mc. When operating between 2 and 3 mc., a shunt antenna capacitor is provided for tuning the antenna to resonance. The capacitor (Type CU–24/ART–13) is connected across the terminals of the coupling network.

Crystal Frequency Indicator System.—The transmitter contains an internal calibration system, the CFI, or crystal frequency indicator. The CFI circuits produce a 50-kilocycle signal together with many harmonics, or multiples, of 50 kc. The harmonics are used as standard signals for use in calibrating the frequency control dials so that the dial settings correspond to actual values of operating frequency. The 50-kc. signal and the harmonic frequencies are controlled by a crystal oscillator which insures accuracy in the standard frequency values.

The circuits which produce the calibration signals are shown in simplified schematic form in figure 7–4.

The CFI oscillator, tripler, and mixer circuits form a

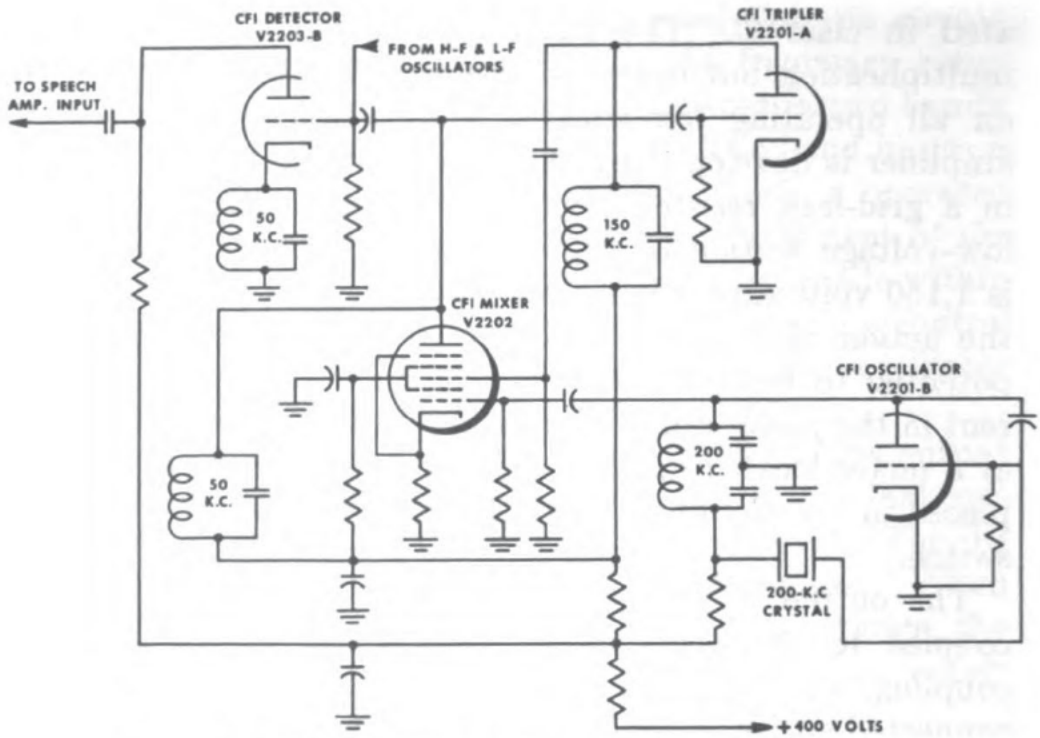


Figure 7-4.—Simplified schematic diagram of the CFI circuits.

regenerative frequency divider, which develops a 50-kc. output under the control of the 200-kc. crystal.

The 200-kc. output signal from the oscillator is coupled to the injector grid (G1) of the CFI mixer tube, a 12SA7. When voltage is first applied to the circuits, the plate circuit of the mixer tube contains many frequency components, some of which are caused by random noise voltages. The mixer plate circuit is tuned to 50 kc. and this component of the random noise frequencies is selected by the tuning circuit and applied to the grid of the CFI tripler, V2201–A. The tripler tube is one section of the 12SL7 twin-triode. The plate circuit of the tripler is tuned to 150 kc., the third harmonic of the 50-kc. input signal. The 150-kc. signal developed in the plate circuit of the tripler is coupled back into the signal grid (G3) of the mixer tube, V2202.

As a result of this action, the electron stream comprising the plate current in the mixer tube is controlled by two signals, the 200-kc. output of the crystal oscillator and the 150-kc. output of the tripler. The difference frequency

resulting from mixing these two voltages appears as a strong 50-kc. component in the mixer plate circuit which sustains the oscillation in the mixer tuning circuit.

The 50-kc. mixer output is coupled to the grid of the CFI detector, V2203–B, one section of the 12SL7GT twin-triode tube. The detector circuit produces many harmonics of 50-kc. When, in addition to the mixer output, a signal from either the low-frequency or high-frequency oscillator is applied to the detector, audible beat frequencies are produced in the detector every 50 kilocycles as the oscillator is tuned across the operating range. The beat frequencies are difference frequencies between the oscillator signal and the harmonic nearest it in frequency. The audible frequencies are coupled to the input of the speech amplifier and can be heard in the headphones in the output of the sidetone amplifier. When the oscillator is adjusted to give zero beat with a harmonic, the oscillator frequency is equal to the harmonic frequency.

During calibration of the control dials, the oscillator is adjusted to the value of the check frequency and the control dials are then set to the reading corresponding to the known frequency.

One section of the 12SL7GT tube which contains the CFI detector is used as an audio oscillator tube. The audio oscillator supplies a 1,000-cycle voltage which is employed for monitoring the keying in CW operation and for modulating the carrier in MCW operation. The oscillator has no function in the CFI circuits but is controlled by means of a cathode bias resistor common to the oscillator and the CFI mixer. When the CFI circuits are being used for calibration, the mixer tube is operative and draws considerable cathode current through the common resistor. The current is sufficient to develop cutoff bias for the oscillator tube. This prevents the oscillator from applying 1,000-cycle energy to the CFI detector where such a signal would affect the calibration signals.

When the CFI unit is not in use, the bias developed across the common resistor is low, thus allowing the oscillator

to operate. An inoperative CFI oscillator results in the production of a constant 1,000-cycle tone.

AUDIO-FREQUENCY SYSTEM.—The audio system consists of an audio speech amplifier, a driver amplifier, a push-pull modulator stage, a sidetone amplifier, and an MCW audio oscillator.

Either a carbon or a dynamic microphone may be used in the input circuit of the first audio amplifier. Transformer coupling is employed between microphone and grid circuit. The amplifier circuit contains a 12SJ7 pentode, the output of which is coupled through an R–C coupling circuit to the grid of a 6V6GT audio driver tube.

The output of the driver is applied both to the modulator grids by transformer coupling and to the input of the sidetone amplifier by means of R–C coupling.

The modulator consists of two type 811 high-mu triodes connected in push-pull. The tubes are operated in class B. The audio output of the modulator tubes is applied to both the screen and the plate of the final r-f amplifier through a modulation transformer. The output audio power developed is sufficient for modulating the r-f carrier up to 90 percent with full voltage applied to the power amplifier plate.

The normal plate potential of the modulator tubes is 1,150 volts. This value is reduced to 750 volts by the action of the pressure-actuated relay during operation at high altitudes.

When the transmitter is operated in CW emission, the modulator stage is inoperative. The plate voltage is removed from the tubes and the section of the modulation transformer attached to the power amplifier plate is shorted by the action of a relay.

The sidetone amplifier provides the operator with a means of monitoring voice signals, CW–MCW keying, or the audio tone generated by the audio oscillator. A portion of the output of the audio driver amplifier is fed into the grid of the sidetone amplifier, a 6V6GT beam pentode tube. The output of the stage is coupled through a matching transformer either to headphones or to a speaker. This

output circuit is keyed by the operation of the keying relay in CW operation.

The plate and screen voltage for the sidetone tube are taken from a voltage divider system in the low-voltage section of the dynamotor.

RADIO SET AN/ARC-27

Radio Set AN/ARC–27 is an example of ultrahigh-frequency communications equipment designed for aircraft installation. The set is a transceiver, a combination of transmitting and receiving equipment contained in a single housing with many of the circuits functioning in both types of operation.

In construction and use, the AN/ARC–27 exhibits the advantages gained by employing the ultrahigh-frequency (uhf) region of the spectrum for aircraft communication. Many more operating channels are available than can be found in the comparatively crowded lower frequency bands. The static interference which is very troublesome in low-frequency radio reception is negligible in the ultrahigh region. Antennas resonant to these frequencies are comparatively small in size and hence are well adapted for aircraft use. The components of the equipment are usually small and light in comparison with low-frequency applications.

A disadvantage associated with operation at frequencies employed by this set lies in the restriction of the range of communication to line-of-sight limits. Ultrahigh-frequency waves are not effectively returned to earth by the ionosphere. Hence, the operating range is limited by the curvature of the earth and confined to areas enclosed by the horizon.

In discussion of this equipment, the present account is concerned only with the major functions of the set. Detailed schematic drawings and exact description of all the various elements cannot be given here, and the reader is referred to the *Handbook of Service Instructions* for information pertaining to the circuit details and maintenance procedures.

Purpose of the Equipment

Radio Set AN/ARC–27 is a transmitter-receiver used for amplitude-modulated, radiotelephone communications between aircraft, between aircraft and shore installations, and between aircraft and ships.

In operation the set may be considered as consisting of three major components: the main channel receiver, the guard channel receiver, and the transmitter. Many circuits are common to the receiving and transmitting functions.

The set operates in the range of frequencies from 225 to 399.9 megacycles. Within this range, 1,750 channels are provided at 0.1 mc. intervals. Tuning and channel selection is accomplished automatically by means of an autotune system. Using a remote control unit, the pilot can select any one of 18 preset operating channels. In addition provision is made for reception and transmission on a guard channel.

The transmitter normally produces voice-modulated signals but it can also be modulated by a 1,020-cycle tone for emergency use and for direction finding purposes.

Electrical Characteristics

The set is operated from a 27.5-volt, d-c power source. The current required at 27.5 volts is as follows:

Operating condition	*Amperes required*
Reception	16. 5
Transmission	19. 1
Channel switching	25. 5

The output power of the transmitter is 9 watts. The main channel receiver develops 50 milliwatts of audio power in a 300-ohm resistive load when the r-f signal input is 5 microvolts. The maximum output power developed by either the main channel or the guard channel receiver is 2 watts.

Description of Major Units

The major units of the AN/ARC–27 equipment include a receiver-transmitter, RT–178/ARC–27, the operator's con-

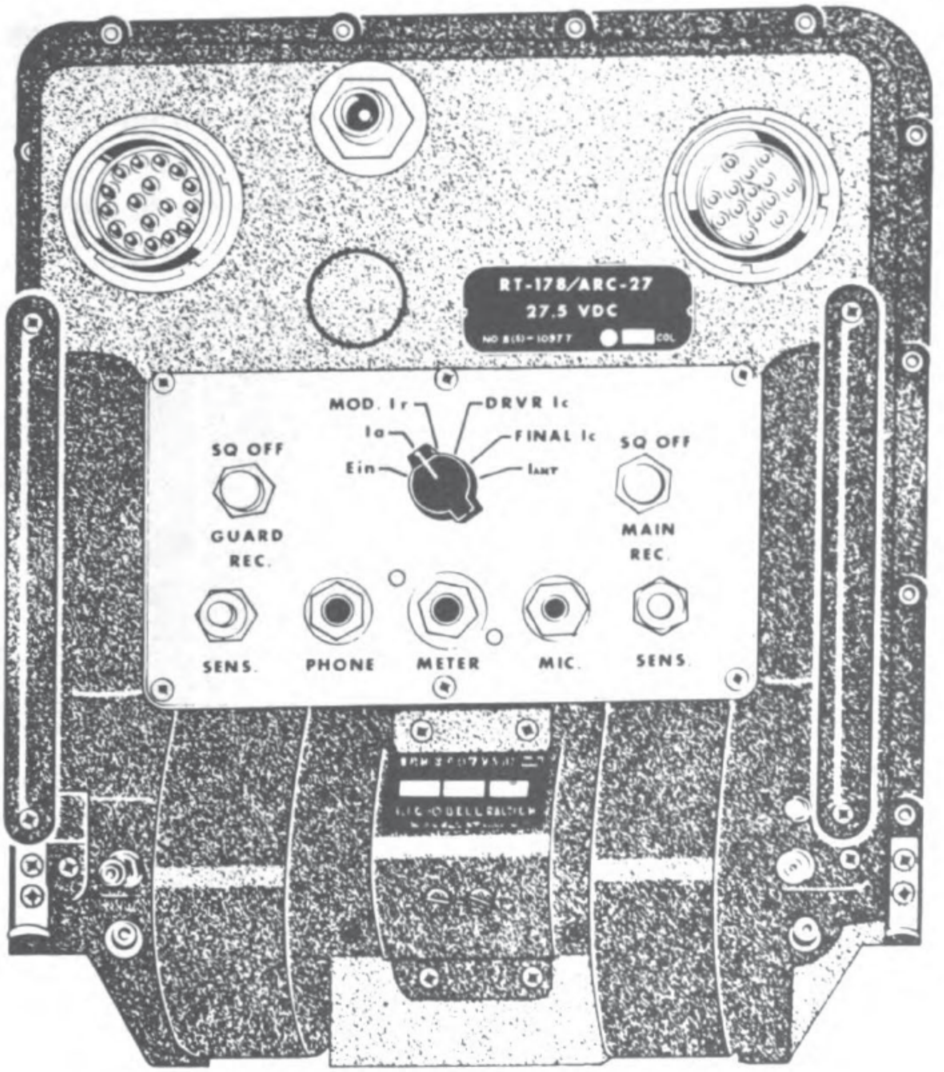


Figure 7–5.—Receiver-transmitter RT–178/ARC–27.

trol unit, C–626/ARC–27, and the pilot's unit, C–628/ARC–27.

The receiver-transmitter is shown in figure 7–5. The unit weighs 70.5 pounds and is enclosed in a pressurized, aluminum case. Pressurization of the enclosure with dry air assists in preventing voltage breakdown when the unit is operated at high altitudes. The case also performs the functions of protective cover, electrical shield, and heat exchanger.

The entire receiver-transmitter is composed of 11 groups of plug-in subassembly units which are interchangeable from one set of equipment to another. The front panel of the unit contains the sensitivity controls of the main and guard

channel receivers, the squelch circuit controls, a meter jack, a meter switch, and headset and microphone jacks. The receiver-transmitter is mounted on a plate which contains four shock absorbers.

The operator's control unit, C–626/ARC–27, is shown in figure 7–6.

Figure 7–6.—Radio Set Control C–626/ARC–27.

Three frequency selector knobs are included in the operator's control unit. Each of these sets a selector switch associated with an autopositioner unit in the receiver-transmitter unit. The autopositioners tune the equipment to the frequency indicated on the control unit. Preset channels may be selected either by the local channel selector on the unit shown or from the pilot's control unit.

The method of setting the operating frequency on each of the 18 channels and the guard channel by use of the operator's control unit is illustrated by the following procedure.

The Local-Remote switch is set to the LOCAL position, and the equipment is turned on. The COMD T/R position of the function switch is selected. The Local Channel

Selector switch is set to the number of the channel to be adjusted, for example, channel 1. The three wing nuts are loosened and the frequency control knobs are rotated until the numerals in the windows indicate the frequency desired for channel 1. The wing nuts are then tightened and the Local Channel Selector switch shifted to any position other than that of channel 1. Upon returning the Local Channel Selector switch to position 1, the frequency selected should again appear in the numerals within the windows. The same procedure is repeated for the other 17 channels. To set the guard channel frequency, the function switch is placed in the GUARD position and the above procedure is repeated. All physical adjustments of the tuning circuits are made by the autotune mechanism and the autopositioner units in the receiver-transmitter.

The pilot's control unit, C–628/ARC–27, contains an audio volume control knob, a channel selector dial, and a function selector switch.

Theory of Operation

The operation of Radio Set AN/ARC–27 in reception and transmission is based on the functions of four principal groups of circuits. These are the main channel receiver, the guard channel receiver, the spectrum system, and the transmitter. In addition, tuning and control is accomplished by means of the autotune and autopositioner units.

The main channel receiver is a triple-conversion superheterodyne containing three crystal oscillators which are provided with automatic crystal selection.

The guard channel receiver is a fixed frequency superheterodyne employing double conversion. The two receivers have a common audio output amplifier.

Many of the circuits in the set are arranged so that signals pass through them in one direction during reception and in the opposite direction during transmission. Excitation signals for the transmitter are produced through a process of frequency conversion, in which the output of a tunable i-f amplifier stage is mixed with the output of a crystal-controlled spectrum generating system. Injection signals

for the first mixer of the main receiver are also produced by the crystal spectrum circuits.

The spectrum system contains a crystal oscillator, harmonic generator stages, and frequency mixers; and by combining signals of various frequencies, it produces the frequency range from 200 to 370 mc. in steps of 10 mc.

Main Channel Receiver

The block diagram of the main receiver is shown in figure 7–7.

In construction, the main receiver is composed of a number of subassemblies, some of which are also used in transmitter operation.

The r-f amplifier section is used only in reception. It contains two stages of grounded grid amplifiers employing 6J4 triode tubes. The grids are grounded to r-f by capacitors which are specially constructed of flat plates and mica spacers. The capacitors are built into the chassis adjacent to the tube sockets. The input signals are applied to the cathode circuits of the r-f amplifiers. Selectivity is provided by three tuned circuits with the variable elements ganged and controlled by a shaft operated by the automatic tuning system. In both tubes, avc voltage is applied to the grids to control the gain with strong input signals.

The output of the second r-f amplifier is coupled to the cathode of a 6AG5 mixer tube where the incoming signal is converted in frequency by mixing it with the injection signal supplied by the spectrum amplifier. Coupling of the local injection signal to the mixer cathode is made by means of the capacitance between two conductors of a short length of specially constructed cable.

The difference frequency obtained by mixing is coupled from the mixer to the input of the 20–30 mc. intermediate amplifier subassembly. The coupling is made through connectors which consist of flat springs and button contacts.

The 20–30 mc. intermediate amplifier subassembly contains two stages of i-f tubes followed by a mixer. These stages have variable tuning provided by adjustable i-f

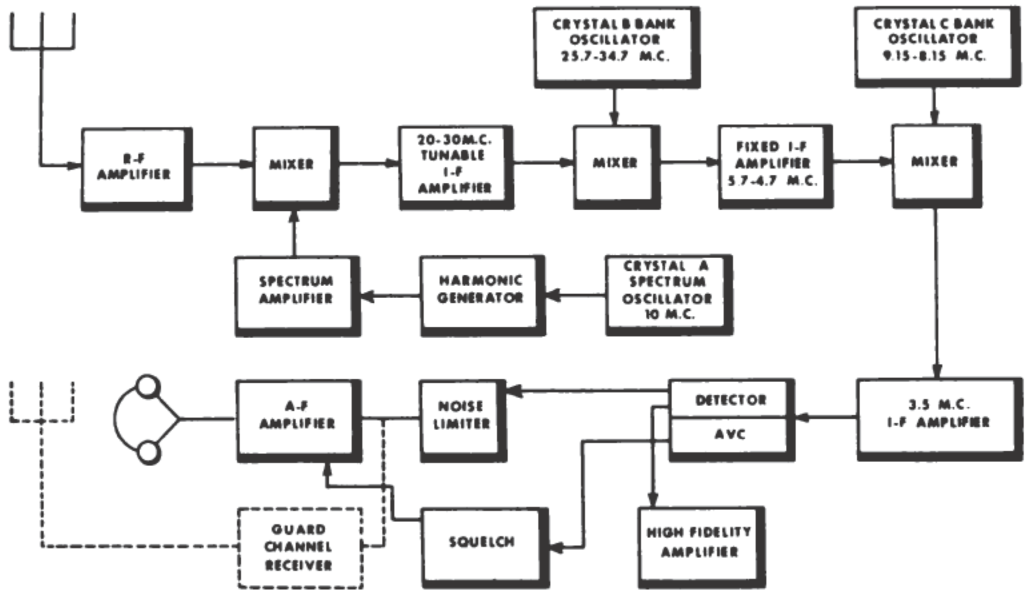


Figure 7-7.—Main receiver block diagram, AN/ARC-27.

transformers. Tuning of the transformers is accomplished by powdered-iron slugs which are controlled in position by the automatic tuning system. Following the second i-f amplifier is a 6AG5 pentode mixer. In this tube a second conversion of the incoming signal is made by combining the 20–30 mc. output with a local injection signal produced by a 12AT7 crystal oscillator. Ten crystals are available in the oscillator circuit. A switch ganged with the i-f tuning adjustments is employed to select the appropriate crystal for a given i-f signal. The range of frequencies produced by the crystal oscillator extends from 25.7 to 34.7 mc., and combination of these values with the i-f signals give a new range of i-f signals from 4.8 to 5.7 mc.

The subassembly containing the 20–30 mc. i-f amplifiers used in reception also contains three 6AG5 pentode amplifiers which operate only during transmission. The same coupling transformers are used both for receiving and transmission. The coil which serves as a transformer primary during reception serves as a transformer secondary during transmission. In this arrangement, the transmitter signal travels through the subassembly in the direction opposite to the path of the received signal. These circuits are called "bilateral amplifiers."

After the second conversion, received signals are applied to the 4.8–5.7 mc. intermediate-frequency amplifier subassembly. This section contains two amplifiers followed by another mixer, and is similar in layout to the previous bilateral i-f section. It contains one set of tubes for receiver operation and another for transmitter operation. The 4.8–5.7 mc. amplifiers do not contain variable tuning elements.

The output signal from the second i-f section is applied to the third mixer where it is combined with the output of a crystal oscillator controlled by one of the crystals in the C bank. The difference frequency signal resulting from this action is applied to the input of the first of three i-f amplifier circuits which are tuned to 3.45 mc.

The Cathode-Coupled Oscillator

The local oscillator in the 20–30 mc. i-f subassembly of the main receiver-transmitter is a cathode-coupled, crystal-controlled circuit called a Butler oscillator. The same type of circuit is also employed as the first local oscillator in the guard channel receiver. These circuits produce stable injection, or mixing, signals at comparatively high frequencies without the use of numerous frequency multiplying stages. The cathode-coupled oscillator differs somewhat from conventional crystal circuits. One of its advantages is that it permits operation of the crystal at an "overtone" frequency, which is an odd multiple of the fundamental crystal frequency.

The cathode-coupled Butler oscillator used in the main receiver provides ten output frequencies from 25.7 to 34.7 mc. in one-megacycle steps. Provision is made for switching one of ten crystals into the circuit to cover this range. A simplified schematic diagram of the circuit is shown in figure 7–8.

The crystal is connected between the cathodes of a 12AT7 twin-triode tube, and the tank circuit is automatically adjusted to the appropriate setting by the tuning mechanism.

The circuit contains a grounded-grid amplifier, V207–A, and a cathode follower, V207–B. The crystal is used as a

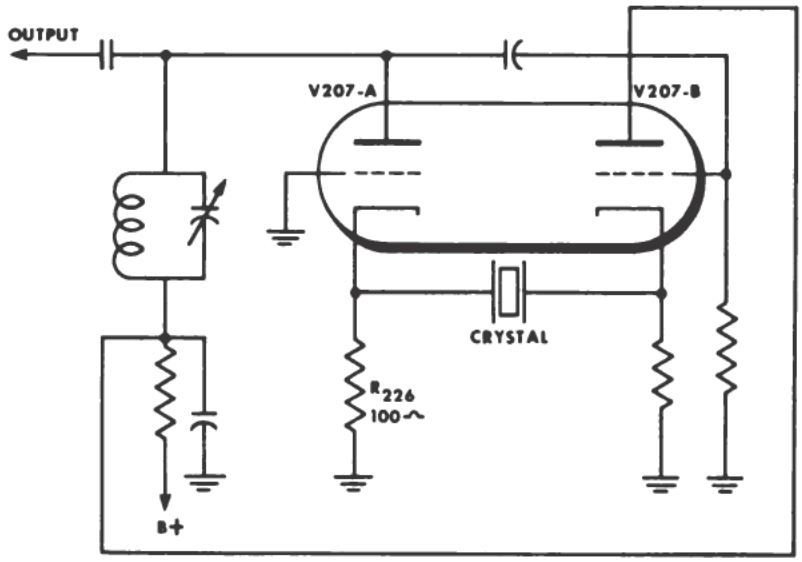


Figure 7-8.—Butler oscillator circuit.

series-resonant wave filter which couples feedback variations from the cathode follower to the grounded-grid amplifier input and which determines the frequency of the feedback signals.

The grounded-grid tube, V207–A, supplies the energy necessary to sustain oscillation in the tank circuit connected to the plate. The conditions required for oscillation are similar to those in conventional oscillators. An output signal of sufficient amplitude to overcome the energy losses in the tank circuit must be fed back in phase with the input signal. In the case of V207–A, the input signal appears across R226 in the cathode circuit. The feedback variations are coupled from the plate of V207–A through the cathode follower stage and the crystal back to R226.

The action of the feedback circuit is such that if the cathode of the grounded-grid amplifier swings positive in potential, a positive pulse is returned to it. When the cathode swings negative, a negative pulse is returned. For example, assume that the grounded-grid amplifier is conducting and that the cathode changes in voltage, swinging in a positive direction. A positive swing at the cathode will decrease the plate current in the tube and cause the plate voltage to increase. The positive-going plate voltage variation is coupled through a capacitor to the grid of V207–B, the

cathode follower, with the result that the plate current increases and the cathode is driven in the positive direction. This positive pulse is coupled through the crystal to R226, driving the cathode of V207–A with a positive-going variation. Thus the polarity of the feedback variation is the same as that of the original change in voltage which initiated the feedback action.

The cathode-coupled circuit works well with almost any crystal and has good frequency stability. It produces adequate output for frequency conversion and has good starting characteristics.

Main Receiver Audio System

The amplified i-f output at 3.45 mc. is applied to a diode detector and to an avc rectifier. The audio signal derived from the detector is applied to the first audio amplifier through a series noise limiter diode which removes any high amplitude noise impulses. The noise limiter circuit contains an additional shunt diode limiter which effectively short-circuits the secondary of the i-f transformer for the duration of the noise pulse. This prevents the noise voltage from affecting the avc circuit with a resulting lowering of the gain of the i-f and r-f amplifiers.

After passing through the noise limiting circuit, the audio signals are coupled to the grid of the first audio amplifier tube. This tube is controlled by the action of a squelch circuit which disables the a-f amplifier in the intervals of standby operation when there is no carrier applied to the receiver input. When no signals are being received, the avc circuit permits the squelch tube to draw high current through a resistor connected between the grid and cathode of the first audio amplifier tube. The resulting voltage-drop biases the a-f amplifier grid to cutoff so that any random noise voltage present in the input of the audio system is not amplified and passed on to the phones.

When a carrier is applied to the receiver, the action of the avc circuit causes a negative bias-supply voltage to be applied to the grid of the squelch tube. The squelch current is cut

off, reducing the bias on the a-f amplifier grid and allowing the amplifier to operate.

The audio output of the detector is amplified in three stages of a-f amplification and is applied to the output phone jacks. The maximum output power that can be developed by the final audio amplifier is about two watts.

A portion of the audio output of the detector is applied to the input of a cathode follower stage which couples audio signals in the range of 20 to 20,000 cycles per second to a pin connection in the receiver-transmitter. This output is used to operate the AN/ARA–25 radio compass.

Automatic Volume Control Circuit

Amplified avc voltage for both the r-f and i-f amplifiers is obtained in the circuit shown in figure 7–9.

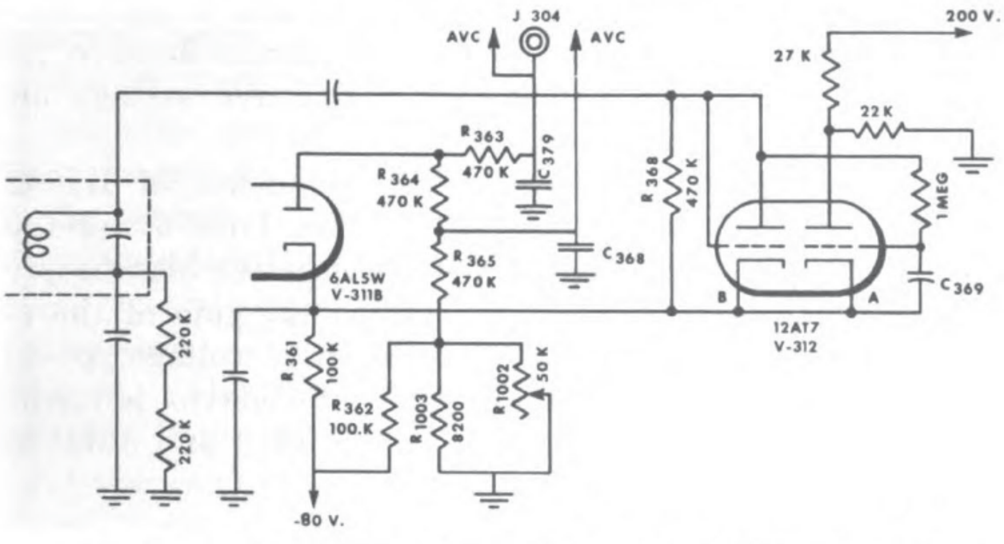


Figure 7–9.—AVC Circuit, Receiver-Transmitter, RT–178/ARC–27.

Two values of avc voltage are developed across the resistors, R364 and R365. The values of these voltages are controlled by the conduction of the diode gate, V–311B.

One section, V–312B, of a twin-triode is connected as a diode and used to rectify the applied 3.45-mc. signal. The rectified voltage appearing across R368 controls the plate current in V–312A, the avc amplifier. The plate to cathode current of V–312A flows through R361, developing a voltage-

drop which opposes the negative 80-volt fixed bias applied to the cathode of V–311B. As plate current in V–312A increases, current in V–311B decreases and the avc voltages decrease correspondingly. When plate current decreases in V–312A, the cathode of V–311B is made more negative by the bias supply, increased current flows in V–311B, and the avc voltages developed across resistors R364 and R365 are increased.

When weak signals are received, the negative potential applied to the grid of the triode avc amplifier is so small that high plate current flows in the triode and develops a voltage across R361 which swings the cathode of V–311B less negative. This reduces the diode current and the resulting negative avc voltage on the resistors, R364 and R365.

When strong signals are received, the triode, V–312A, is biased strongly negative by the rectified signal, plate current is reduced, and the cathode of V–311B assumes a high negative potential. As a result, maximum current flows in the diode gate, and high values of negative avc voltage are developed across the resistors.

Receiver sensitivity is controlled by means of R1002. This resistor is combined with R362 to form a voltage-divider which is connected across the negative bias supply. R1002 provides a means of controlling the gain of the r-f and i-f amplifiers by control of the negative voltage applied to the avc lines. For maximum gain, the control is turned full clockwise, moving the junction of R362 and R365 to ground potential.

Guard Channel Receiver

The guard channel receiver is a dual-conversion superheterodyne. The principal stages are shown in the functional block diagram of figure 7–10.

As shown in the diagram, the output of the guard receiver is derived from the same stages which serve as final audio amplifiers in the main channel receiver. Otherwise the two receivers operate independently.

One stage of r-f amplification, containing a 6AK5W pentode, and three tuned circuits are provided. The tuned

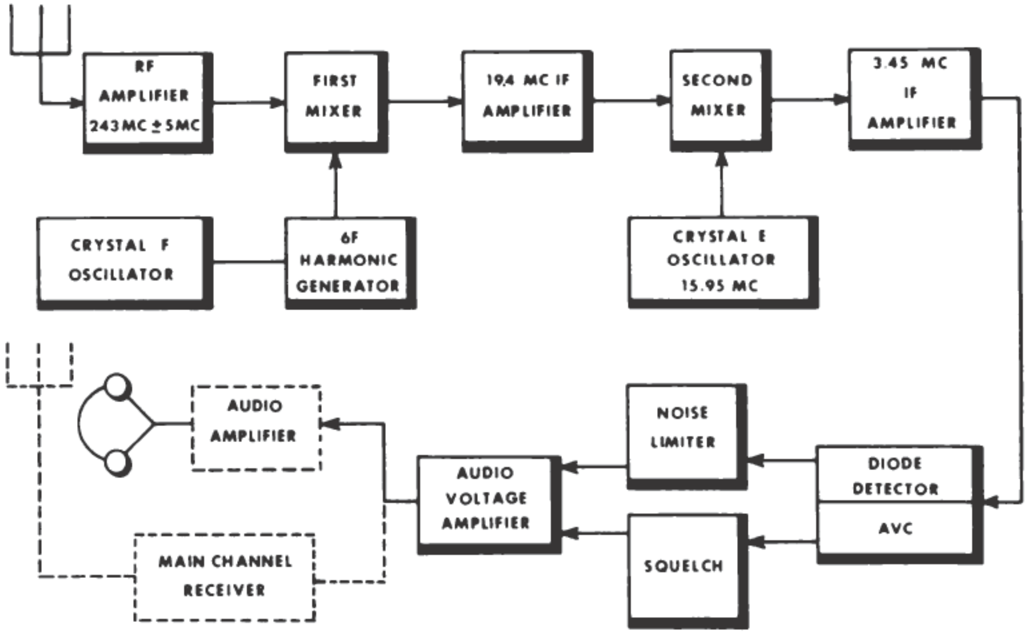


Figure 7–10.—Guard channel receiver block diagram.

circuits insure sufficient selectivity to prevent image-frequency reception.

Injection voltage for the first mixer is supplied by a cathode-coupled crystal oscillator and a frequency multiplier system. The crystal frequency (which is 37.266 mc. when the guard frequency is 243 mc.) is multiplied six times to 223.6 mc. and coupled to the cathode of the mixer tube, a 12AT7 twin-triode. The output circuit of the mixer is tuned to 19.4 mc. This value is the difference of the guard frequency and the frequency of the multiplied crystal output.

The output of the first mixer, a 19.4-mc. signal, is amplified in one stage of i-f amplification and the mixing process is repeated to reduce the signal frequency to 3.45 mc. The second injection oscillator is also crystal-controlled, and operates at 15.95 mc. The 3.45-mc. value is produced by combining the i-f signal and the second injection voltage in a second mixer, another 12AT7 tube. Two stages of 3.45-mc. amplification are used.

The guard receiver audio system includes a diode detector, a noise limiter, an avc rectifier and avc amplifier, a squelch tube, and an audio voltage amplifier. These circuits operate independently so that strong signals in the main

channel receiver do not affect the avc and gain of the guard channel receiver.

The Spectrum Generating System

The spectrum system is used to provide injection signals for the first mixer of the main channel receiver. It also produces (with a similar process of mixing) the r-f excitation voltage for the final amplifier of the transmitter. The output of the spectrum system covers the range of frequencies from 200 to 370 mc. in steps of 10 mc.

The principal components are shown in block diagram form in figure 7–11.

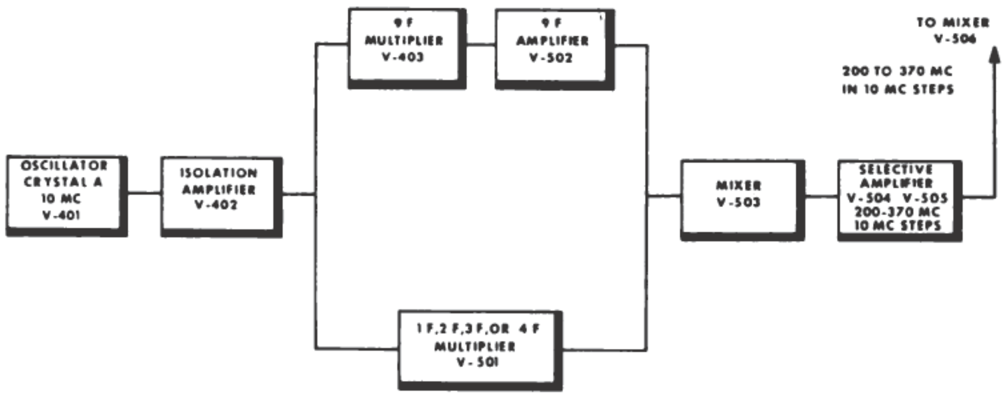


Figure 7–11.—Spectrum system of Receiver-Transmitter RT–178/ARC–27.

The initial stage of the spectrum circuits is a 10-mc. crystal oscillator, V–401, containing a 6AG5 pentode. The control grid, screen grid, and cathode of the tube are connected in a Colpitts-crystal circuit with the crystal connected between control grid and ground. (These elements constitute the oscillator which is electron-coupled to the plate by the plate current.) The crystal is mounted in a holder contained in a thermostatically controlled oven that maintains the crystal at a temperature of 80 degrees C. (176° F.). As a result of the constant crystal temperature, the frequency drift of the oscillator caused by tube effects, temperature effects, and aging is less than 100 cycles.

The 10-megacycle output of the oscillator is applied to the grid of a buffer amplifier, V–402, which serves to isolate

the oscillator from the effects of tuned circuits in the following stages, the multipliers. The buffer tube is a 6AG5 operated as a class A amplifier. The plate circuit is tuned to 10 mc. and is coupled to two sets of frequency multipliers. One of these, V–403, a 6AG5 pentode operated in class C, multiplies the input signal 9 times, producing a 90-mc. output. This is applied to V–502, the output of which contains 90-mc. signals and many harmonics of this frequency.

As indicated in the diagram in figure 7–11, the buffer output is also coupled to V–501, a harmonic generator. The plate circuit of V–501 contains one of four circuits pretuned to 10, 20, 30, and 40 mc. One of the tuning circuits is selected by the tuning mechanism and connected in the harmonic generator by means of a relay.

Signals from both sets of frequency multipliers are applied to a mixer tube, V–503, in which the 10-, 20-, 30-, and 40-megacycle signals are combined with the second, third, and fourth harmonics of 90 mc. to give frequency components in the range of 200 to 370 megacycles in 10-mc. steps. These frequencies are derived in the following ways:

$2\times90+20=200$ mc.	$3\times90+20=290$ mc.
$2\times90+30=210$ mc.	$3\times90+30=300$ mc.
$2\times90+40=220$ mc.	$3\times90+40=310$ mc.
$3\times90-40=230$ mc.	$4\times90-40=320$ mc.
$3\times90-30=240$ mc.	$4\times90-30=330$ mc.
$3\times90-20=250$ mc.	$4\times90-20=340$ mc.
$3\times90-10=260$ mc.	$4\times90-10=350$ mc.
$3\times90-0=270$ mc.	$4\times90-0=360$ mc.
$3\times90+10=280$ mc.	$4\times90+10=370$ mc.

The output of the mixer, V–503, contains numerous signals of different frequency. For operation on a particular channel, one of these components must be selected and the others tuned out. This is accomplished by applying the mixer output to a frequency amplifier consisting of V–504 and V–505. These are two 6J4 tubes operating in conjunction with three variable tuning circuits which are ganged and tuned in 10-megacycle steps. Adjustment of the tuning circuits is made automatically by the action of the channel

selecting mechanism which alines the tuning elements in accordance with the setting of the frequency dials of the control unit.

In transmitter operation, one of the signals developed by the spectrum system is combined with a signal taken from the output of the 20–30 mc. intermediate-frequency assembly. The combination is made in V–506, the transmitter mixer, which produces signals equal in frequency to the sum of the applied frequencies. By combination of components in the ranges of 200 to 370 mc. and 25 to 29.9 mc., transmitter excitation signals are obtained which range in frequency from 225 to 399.9 megacycles.

In receiver operation, the spectrum system acts as a local oscillator for the first mixer stage. The incoming signals are within the range of 225 to 399.9 mc. Combination of these with the spectrum system output produces intermediate-frequency components within the tuning range of the 20–30 mc. i-f amplifiers of the receiver.

Transmitter Operation

The transmitter section of the AN/ARC–27 equipment is shown in block diagram form in figure 7–12.

The transmitter generates and radiates signals in the 225 to 399.9 mc. range with a carrier power of about 9 watts. The carrier frequency is generated by mixing the output of the spectrum amplifier with the output of the 20–30 mc. i-f amplifier subassembly.

The 20–30 mc. output signal is produced by mixing the voltages developed by the B, C, and D crystal oscillators in the arrangement shown in figure 7–12. The process begins in the D oscillator, a crystal-controlled Colpitts circuit, which is used only in transmitter operation. The D oscillator generates a 3.45-megacycle voltage and couples it to a mixer tube to which the output of the C oscillator is also attached. The C oscillator generates signals in the frequency range from 8.25 to 9.15 mc. in ten steps of 0.1 mc. One of ten crystals is automatically selected by the tuning mechanism to give the correct value for the operating channel selected at the control unit.

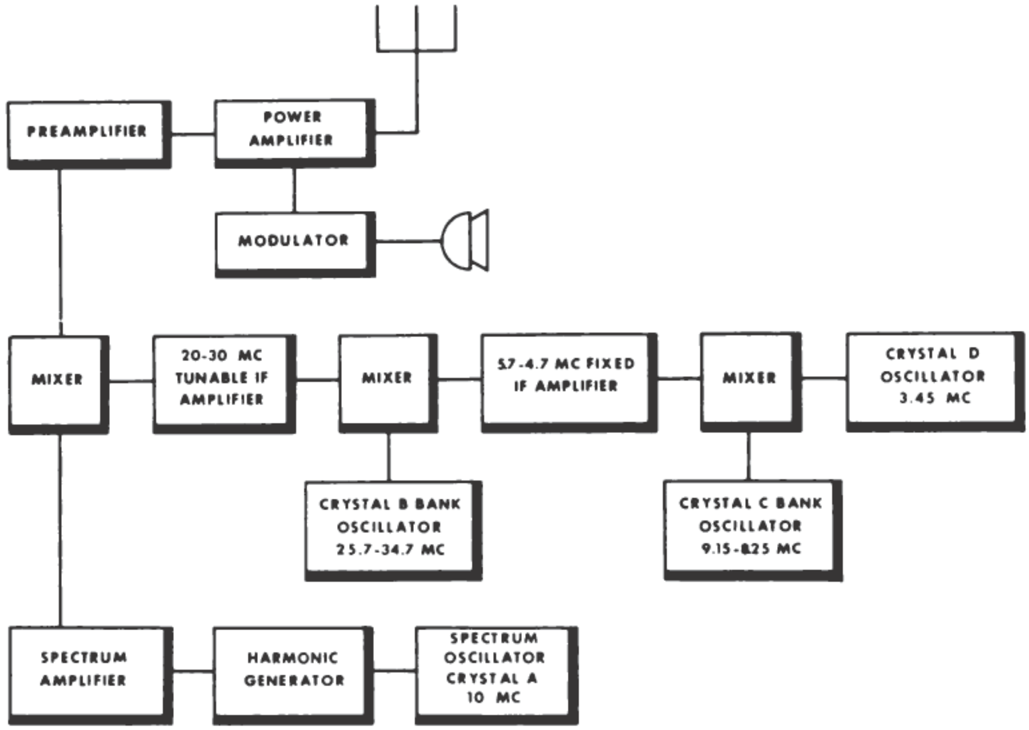


Figure 7-12.—Block diagram of Transmitter, RT-178/ARC-27.

The process of mixing the D and C voltages results in a difference frequency contained in the 4.8 to 5.7 mc. range. The resultant is amplified in fixed tuned amplifiers and applied to a second mixer tube to which the signal from the B oscillator is coupled. The B circuit, the Butler oscillator, generates crystal-controlled signals contained in the 25.7 to 34.7 mc. range.

The second process of mixing gives a difference frequency within the 20–30 mc. band which is amplified in the tunable i-f subassembly. The amplified output of the i-f section is applied to the transmitter mixer tube and combined with the output of the spectrum amplifier. Addition of frequency values occurs in the mixer to give signals in the 225 to 399.9 mc. range. These signals are used for transmitter excitation and after amplification are applied to the input of the power amplifier.

The output of the transmitter mixer is applied to the preamplifier section which selects and amplifies the signal for application to the power amplifier tubes. The preamplifier consists of two grounded grid amplifiers employing 6J4

triode tubes. The grounded grid arrangement is a typical triode circuit for amplification at the frequencies present in this section of the transmitter. The primary feature of the circuit is the shielding action of the grounded grid which effectively reduces the interelectrode capacitance between the input element (the cathode) and the output element (the plate).

The preamplifier contains three tuning circuits which are ganged and tuned by the automatic tuning mechanism. The adjustments are controlled by the settings of the selector dials of the operator's control unit.

The power amplifier section contains three tubes: a 2C39A output amplifier driven by another 2C39A which is driven by a 2C43. These tubes are grounded grid triodes in which the grids are grounded to r-f by capacitors. The input signals in each stage are applied to the cathodes. Resistors are connected between the grids and cathodes to provide d-c return paths. The resistor in the final tube is a potentiometer which is geared to the tuning circuit and it varies over the tuning range so as to lower the gain of the amplifier at the middle frequencies and to raise the gain at the extremes of the range. This action causes the output power to have a nearly constant value at all operating frequencies.

The amplified r-f energy is coupled from the final tank circuit by means of a one-turn loop connected to a short length of coaxial cable. The cable is attached to the antenna through the contacts of an antenna change relay. The same antenna is used both for receiving and for transmitting.

Audio power for modulating the transmitter carrier is developed by a twin-pentode modulator, an 829B, operated in push-pull. The modulator output is developed across an inductance coil in the plate lead connecting the plates of the r-f final tubes to the power supply, and audio modulating voltages are applied to the plates of all three power amplifier tubes.

The modulator is driven by a phase inverter of the cathode follower type employing one section of a twin-triode 12AT7.

The remaining section of the twin triode is an input audio amplifier to which the microphone is coupled through a transformer.

The Channel Selector System

One of the principal requirements of aircraft communications systems is that the pilot and the operator be provided with the means for making rapid and accurate adjustments of the operating frequency. Tuning must be accomplished without the need for setting numerous switches and dials and without the use of bulky components. To meet these requirements, the AN/ARC–27, like the AN/ART–13, is provided with an automatic tuning system with which the various adjustments of tuning circuits and switches are made by motor-driven shafts and gear trains.

The system used in the AN/ARC–27 contains two basic types of mechanisms, the autotune units and the autopositioners. The physical adjustments are made by the autopositioners. The autotune units set the positions of rotary switches which control the operations of the autopositioners.

These units are controlled by the master control, C–626/ARC–27, and by the pilot's remote control box. The master control unit permits selection of any one of 1,733 usable frequencies (frequencies ending in 0.0 are avoided). Selection of one of these is made by setting three dials on the control panel. Operation of these dials causes the autopositioner motor to run, driving various gears and shafts which tune the receiver-transmitter to the frequency selected.

The Local Channel Selector switch of the master control unit controls the action of the autotune units. In accordance with one of the 20 positions of the selector switch, the autotunes set rotary switches which operate the autopositioner motor, causing it to tune the receiver-transmitter to one of 18 preset operating channels or to the guard channel. (The twentieth position permits manual selection of any one of the 1,733 usable frequencies.)

The autotune units are employed in the master control

unit. Each autotune sets a control switch. The three switches determine the operating frequency, and changes can be made in steps of 10, 1.0, and 0.1 megacycles.

A single motor drives all the autotune units through a gear train and a system of slip clutches. The autotune basic elements consist of a cam drum, a stop ring drum, and a pawl stack. These are shown in figure 7–13.

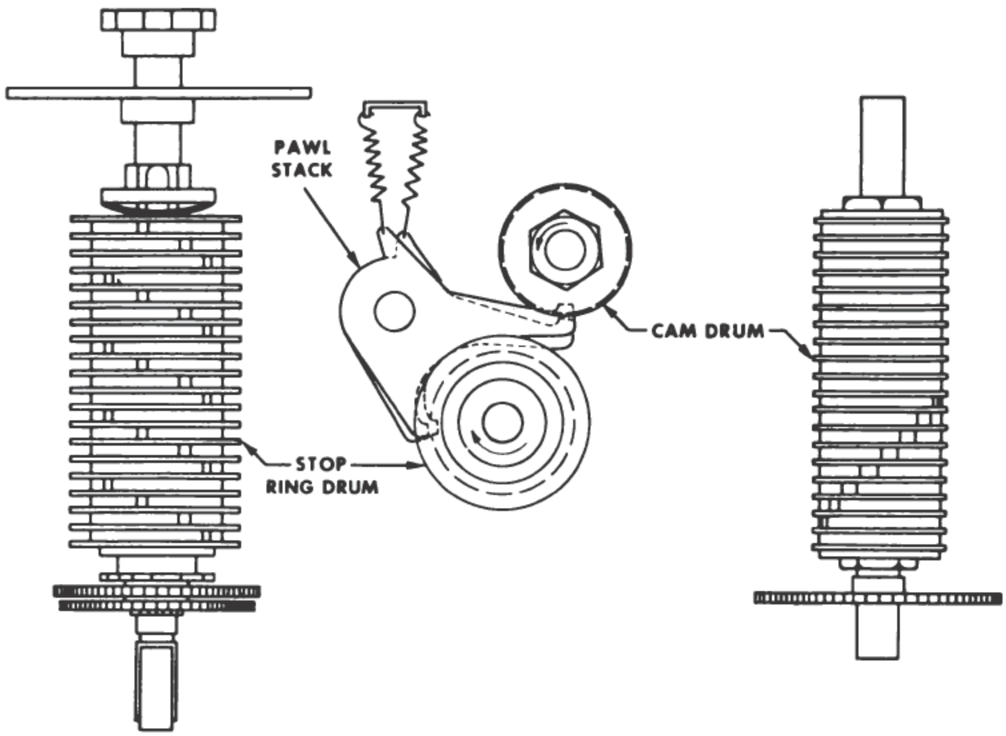


Figure 7–13.—Basic autotune elements, Radio Set Control C–626/ARC–27.

Each drum contains 19 offset slots. Each slot on the cam drum corresponds to a channel. Each position in which the stop ring drum comes to rest corresponds to an operating frequency. The stop ring drum is locked in place when one of the pawls engages slots in both the cam drum and the stop ring drum.

The general nature of the autotune action is as follows: When a channel is selected on the selector switch, a relay is energized, starting a motor which drives both drums through slip clutches. When the cam drum is positioned correctly for the channel selected, a rotary switch on the motor shaft reaches an open position. This results in relay action which

stops the cam drum by dropping a pawl (not shown) into a notched stop-wheel attached to the cam drum shaft. The clutch through which the cam drum is driven begins to slip, allowing the motor to continue rotating and to drive the stop ring drum. When the cam drum stops, one of the pawls, shown in figure 7–13, drops into one of the slots. Since the slots are offset, only one pawl can drop. It is then placed so that it can engage a slot in the stop ring drum, stopping its rotation. The stop ring positions set switches which govern the frequency to which the autopositioners tune the equipment.

The autopositioners are motor-driven units which adjust the tuning circuits and switches of the subassemblies in the receiver-transmitter. Autopositioner tuning action is controlled by the "open-circuit seeking" system, the basic principle of which may be explained by the diagram shown in figure 7–14.

The figure illustrates the principle of operation by showing a system of single-pole, double-throw switches in the circuit of the relay which controls the operation of the motor. The switches on the right, labeled "seeking switches" are operated by the rotation of the motor shaft. When the

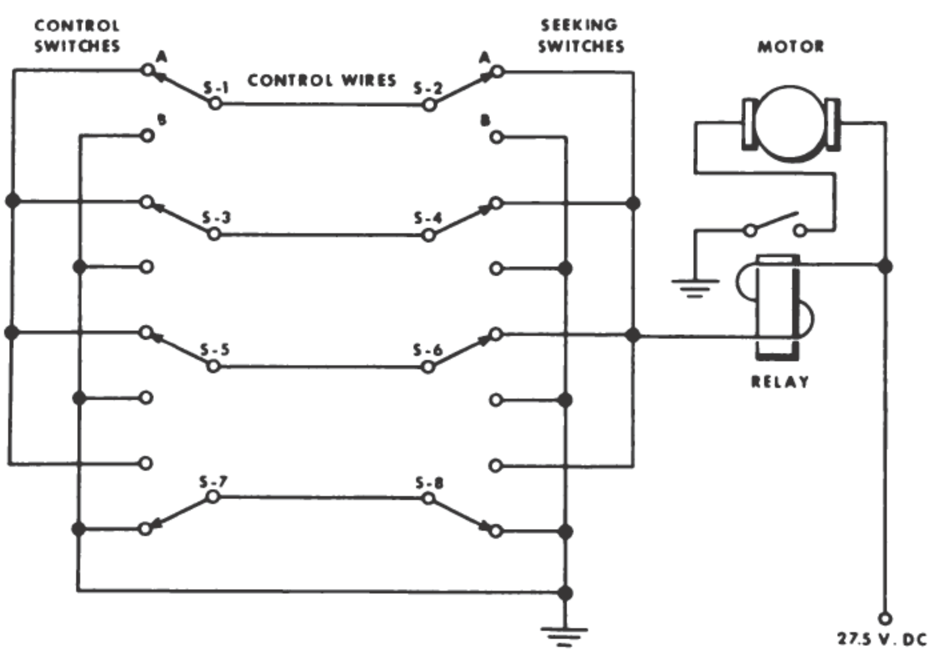


Figure 7–14.—Autopositioner basic diagram.

control switches on the left and the seeking switches are set symmetrically, or with corresponding switches occupying similar positions, there is no current path from the relay coil to the ground. In this condition, the relay remains unenergized and the motor does not run.

When any one of the control switches is set to a position different from that of the corresponding seeking switch, the motor relay is energized and the motor is started. The motor continues to run until the seeking switches, which are repositioned by the motor, reach a setting similar to those of the control switches. This arrangement stops the motor by opening the relay circuit.

A simplified functional diagram of an autopositioner unit is shown in figure 7–15, which indicates the elements controlled by the open-circuit seeking principle.

The basic elements of the autopositioner are a motor with a gear reduction train, a slip clutch, a rotary shaft to which

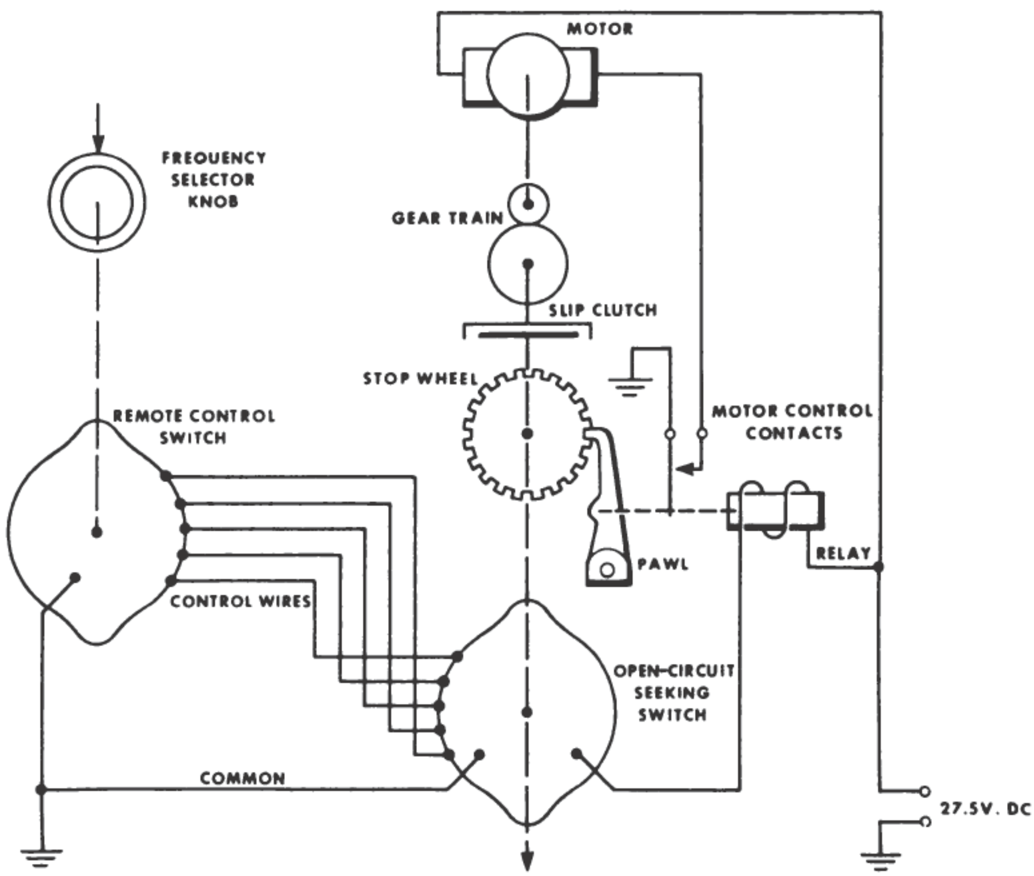


Figure 7–15.—Simplified functional diagram of an autopositioner unit.

is fastened a notched stop-wheel, a pawl which engages the notches of the stop-wheel, a relay for operating the pawl and controlling the motor, and a set of electrical contacts comprising the control system.

The cycle of operation of the autopositioner unit is as follows:

1. The system is at rest with the control and seeking switches in corresponding positions.
2. The operator changes the setting of the frequency selector knob.
3. The relay is energized, lifting the pawl out of the stop-wheel and closing the motor control contacts, starting the motor.
4. The motor drives the autopositioner shaft and the rotor of the seeking switch until a position corresponding to the new position of the control switches is reached. Rotation of the motor shaft sets various switches and tuning elements in the receiver-transmitter. When the setting corresponding to the selector position is reached, the open-circuit seeking switches correspond to the control switches. The relay circuit is opened, the pawl engages the stop-wheel and the control shaft is brought to a quick stop. The motor coasts to a stop, dissipating the rotating energy in the slipping clutch.

RADIO SET AN/ARC–27A

The equipment bearing the designation AN/ARC–27A is a modification of AN/ARC–27. An installation of AN/ARC–27A contains the same type of receiver-transmitter unit employed in AN/ARC–27. The principal difference between the two sets pertains to the control system in use.

The list of basic units in the AN/ARC–27 installation includes one or two receiver-transmitters, one or two C–626/ARC–27 control boxes, one optional control unit for use by the pilot, and the required mounting racks. The AN/ARC–27A basic units consist of one or two receiver-transmitters, the necessary mountings, and one of the following control units: C–1015/ARC–27A; C–1024/ARC–27A; or C–1025/ARC–27A.

Either radio set is capable of providing transmission and reception on any one of 1,750 channels in the band of 225 to 399.9 megacycles. And it is also possible to monitor one predetermined guard-channel frequency. In both equipments, the control units permit manual selection of any usable frequency within the frequency range of the system. In AN/ARC–27 sets, selection of one of eighteen preset channels or of the guard channel is possible. In the AN/ARC–27A equipment, selection can be made of any one of twenty preset channels or of the guard frequency.

In the operation of the AN/ARC–27 set, the frequencies of the preset channels are determined by settings made at the C–626/ARC–27 control unit which is usually mounted in the radio operator's compartment. In the AN/ARC–27A installation, the preset channel settings are made at the pilot's control unit, which is one of the three listed above. All of the AN/ARC–27A control boxes permit selection of automatic-direction-finding operation in addition to frequency selection; and no provision is made in any of them for tone transmission.

QUIZ

1. The main reason automatic tuning is desirable in airborne radio equipment is
   a. more frequencies can be used
   b. it simplifies maintenance and repair
   c. it withstands vibration and shock better than other types of tuning
   d. tuning adjustments must be made quickly
2. The main reason for decreasing the plate voltage on the power amplifier and the modulator tubes from 1,150 to 750 volts above 25,000 feet in the ART–13 transmitter is to
   a. prevent possible arc-over between the leads in the set
   b. decrease the power output of the set
   c. prevent possible arc-over in the vacuum contacts
   d. reduce current in the power supply at high altitudes

3. The dynamotor (DY–12/ART–13) of the AN/ART–13 aircraft radio equipment supplies which of the following d-c voltage or voltages?
   a. 1,150
   b. 28, 400, and 750
   c. 400 and 750
   d. 270, 750, and 1,150

4. The 400-volt output circuit of the dynamotor (DY–12/ART–13) is protected from overload by a
   a. 35-ampere fuse
   b. 5-ampere fuse
   c. 1-ampere fuse
   d. two thermally operated reset-type relays

5. The output power derived from the AN/ART–13 radio transmitter varies with the frequency of operation and ranges from about
   a. 7.5 watts to 105 watts
   b. 5.5 watts to 50 watts
   c. 5.5 watts to 90 watts
   d. 6.5 watts to 90 watts

6. In the transmitter (T–47/ART–13) of the AN/ART–13 radio equipment the type of tube used as the high-frequency oscillator is
   a. 1625 pentode
   b. 12SL7 twin-triode
   c. 811 triode
   d. 837 pentode

7. In the AN/ART–13 radio equipment a shunt antenna capacitor (Type CU–24/ART–13) is provided for tuning the antenna to resonance between
   a. 3 mc. and 18.1 mc.
   b. 2 mc. and 18.1 mc.
   c. 2 mc. and 3 mc.
   d. 1,000 kc. and 1,510 kc.

8. The purpose of the microphone circuit in the AN/ART–13 transmitter is to
   a. match a carbon microphone only to the first audio
   b. match the dynamic and crystal microphones to the first audio
   c. match either the carbon or dynamic microphone to the input of the first audio
   d. make the impedance of both the carbon and dynamic microphones the same

9. The AN/ART–13 transmitter when used on voice emission will modulate the r-f carrier up to
   a. 100 percent
   b. 50 to 80 percent
   c. over 100 percent
   d. up to 90 percent

10. The screen voltages of the multiplier tubes used in the AN/ART–13 transmitter are reduced from 800 volts to 270 volts by use of
    a. a transformer tap
    b. a rheostat
    c. series resistors
    d. voltage divider networks

11. The low-frequency oscillator of the AN/ART–13 transmitter covers the frequency range of
    a. 2.0 mc. to 2.5 mc.
    b. 1,200 kc. to 1,500 kc.
    c. 200 kc. to 1,500 kc.
    d. 1.2 mc. to 1.5 mc.

12. The first frequency multiplier of the AN/ART–13 transmitter may be operated as a
    a. doubler or tripler
    b. tripler only
    c. quadrupler only
    d. doubler, tripler, and quadrupler

13. In the AN/ART–13 transmitter the power amplifier stage contains an 813 tube using
    a. fixed bias
    b. grid-leak bias
    c. cathode bias
    d. combination of cathode and fixed bias

14. The high-frequency oscillator circuit of the AN/ART–13 transmitter is of the type known as a/an
    a. modified Hartley circuit
    b. Armstrong circuit
    c. electron-coupled Colpitts circuit
    d. crystal-controlled oscillator

15. The AN/ARC–27 radio equipment has 1,750 available frequencies at intervals of
    a. 10 mc.
    b. 1.0 mc.
    c. 0.1 mc.
    d. 0.01 mc.

16. The B-Bank (Butler) oscillator develops a frequency which may be changed in steps of
    a. 0.1 mc. each
    b. 10 mc. each
    c. 1 mc. each
    d. 3.45 mc. each

17. The output of the spectrum generating system of the AN/ARC–27 radio equipment covers the range of frequencies from
    a. 200–370 mc. in steps of 10 mc.
    b. 225–399.9 mc. in steps of 10 mc.
    c. 200–399.9 mc. in steps of 1 mc.
    d. 200–370 mc. in steps of 1 mc.

18. The output power of the transmitter in the AN/ARC–27 radio equipment is
    a. 2 watts
    b. 5 watts
    c. 9 watts
    d. 50 watts

19. The AN/ARC–27 radio equipment operates in the range of frequencies from
    a. 100 to 156 mc.
    b. 225 to 399.9 mc.
    c. 400 to 859.5 mc.
    d. 550 to 1600 kc.

20. By using a remote control unit with the AN/ARC–27 radio set the number of preset operating channels that can be selected are
    a. 11 and the guard channel
    b. 12 and the guard channel
    c. 18 and the guard channel
    d. 20 and the guard channel

21. In the main channel receiver of the AN/ARC–27 radio set the output of the second r-f amplifier is coupled to the
    a. control grid of a mixer tube
    b. cathode of a mixer tube
    c. injection grid of a mixer tube
    d. plate and screen of the RFPA

22. One of the principal advantages of the Butler oscillator is that
    a. it can be used for very low frequencies
    b. the output is greater than in most oscillators
    c. only one crystal is required to provide a band of frequencies
    d. it permits operation of the crystal at an "overtone" frequency

23. Which of the following is true of the main and guard channel receivers of the AN/ARC–27 radio set?
    a. Both use the same 3.45 mc. i-f strip
    b. Both use a common audio and detector stage
    c. Operate independently except for common audio amplification
    d. Both have their voltage taken from the same point

24. Referring to figure 7–13, each of the 19 offset slots on the cam drum corresponds to a/an
    a. frequency
    b. channel
    c. switch
    d. r-f signal

CHAPTER 8

AIRCRAFT ELECTRONIC NAVIGATION EQUIPMENT

After World War II great progress was made in the development and application of electronic equipment designed to increase the safety and reliability of aviation. Under the direction of the Civil Aeronautics Administration a vast program was initiated to improve and extend the federal airways system by the use of new devices based on wartime development. Of primary importance was the introduction of VHF omnidirectional range stations which will eventually replace the low-frequency, four-course range stations. The new equipment includes, in addition, instrument landing systems, distance measuring equipment, and navigational computers. For long range navigation, the loran system was retained and the facilities expanded and improved.

This chapter is concerned principally with airborne receiving equipment designed for use with omnidirectional range signals and with loran transmissions. As an introduction to the operation of the omni receiver, a description of the UHF omnirange system and related equipment is given here together with a discussion of the low-frequency radio aids which this system will replace. As an introduction to the loran receiver, the reader is referred to the discussion of the fundamentals of the loran system given in chapter 2.

RADIO RANGES AND RELATED FACILITIES

Low-frequency radio ranges.—A radio range is a continuous-wave station, the radiation from which produces directional courses or tracks. These courses remain stationary with respect to the surface of the earth and serve to guide aircraft over long distances. The older equipment used to produce the range courses consists of low-frequency ground stations operating from about 200 to 400 kilocycles. Associated with the range stations are marker beacon stations. These are transmitters which have limited and highly directional radiation used to give the pilot information concerning his position along the range course.

The low-frequency range station provides four courses. The ground equipment includes two transmitters and five high antenna towers of about 130 feet. The antennas comprise the Adcock system; four towers are located on the corners of a square. The fifth tower is situated in the center of the square. Diagonally opposite towers are separated by a distance of about 600 feet and are operated simultaneously to constitute a pair. Each pair radiates a figure-of-eight pattern in the horizontal plane. The center tower has a radiation pattern which is nondirectional.

The two corner pairs are driven by a crystal-controlled transmitter through a relay which is operated by a motor-driven keyer. The keyer energizes the two sets of antennas alternately. One pair gives a series of dot-dash characters (letter A in code), and the other is keyed with a series of dash-dot (letter N) characters. The center tower is fed by a second crystal-controlled transmitter which develops a carrier frequency which is 1,020 cycles lower than the radiation of the other four antennas. When the combined signals are present in the receiver, a 1,020-cycle output is produced as a beat frequency from the two types of transmissions.

The two figure-eight patterns and the nondirectional emission of the center tower produce a total space pattern as shown in figure 8–1. The signal heard in a receiver depends upon the position of the receiver with respect to the

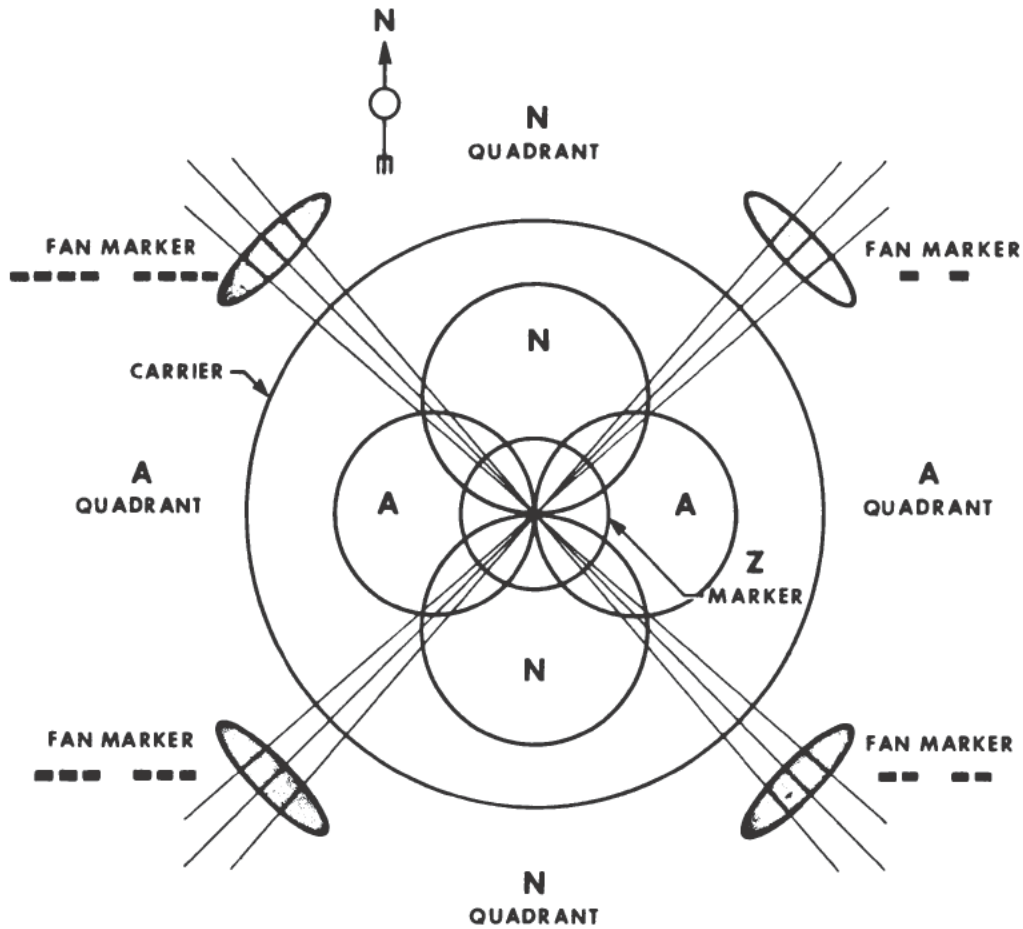


Figure 8–1.—Courses and radiation patterns of the low-frequency range.

antenna system. In those positions where the A and N signals overlap, or exist in equal strength, no separate code character is heard but rather a continuous tone resulting from the interlocking code characters. The areas of overlap determine the four courses provided by the station.

In effect the center tower provides the carrier energy and the corner towers supply sideband power for producing the audible beat note. In addition, the center antenna is used for transmitting voice modulation, and the airborne receiver is equipped with filters so that the pilot can select voice or range signals without interaction. Over each range station a cone of silence exists in which no range signal is heard. This null is used (in connection with a marker transmitter) as a means of determining the position of the aircraft when immediately above the station.

RADIO MARKERS.—As shown in figure 8–1, marker signals are used in conjunction with the range courses to provide for position checking along the route. Two types of marker signals are used, Z MARKERS and FAN MARKERS. The Z-marker transmitter is located at the range station and the signal gives positive identification of the cone of silence. This signal is a crystal-controlled, 75-megacycle emission modulated by a 3,000-cycle tone.

Fan markers are produced by keyed, 100-watt, 75-mc. transmitters located on or near the range course about 20 miles from the range station. The emitted signal is modulated by a 3,000-cycle tone which is keyed in dashes to identify the range leg containing the marker. Starting at north and proceeding clockwise, the dashes increase in number with the course legs. If there are two fan markers located on one leg, the outer marker signal is coded with two dots preceding the dashes.

The airborne equipment used in reception of marker signals is usually a single-frequency superheterodyne receiver which is crystal controlled. The receiver output is filtered and applied to a signal circuit which causes a lamp to glow on the instrument panel when the marker signal is received. The tone is also applied to the pilot's phone circuit to give aural identification of the position. The marker signals are usually radiated from an antenna array consisting of four half-wave elements and a counterpoise. The cross sections of the radiation patterns produced are shown in figure 8–2.

The bone-shaped cross section of the fan marker radiation

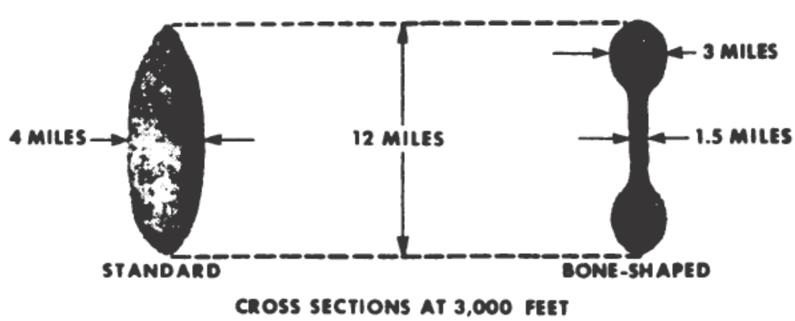


Figure 8–2.—Marker patterns.

is a newer type than the standard section shown at its left. This pattern is employed to give sharper identification than is provided in the standard pattern.

VISUAL-AURAL RANGE (VAR).—The visual-aural range system is a very high-frequency facility which like the low-frequency range provides four courses. The VAR system was developed to eliminate the problems of static and interference present in the low-frequency range and also to facilitate the identification of the range quadrants. As shown in figure 8–3, the four courses consist of two aural and two visual tracks.

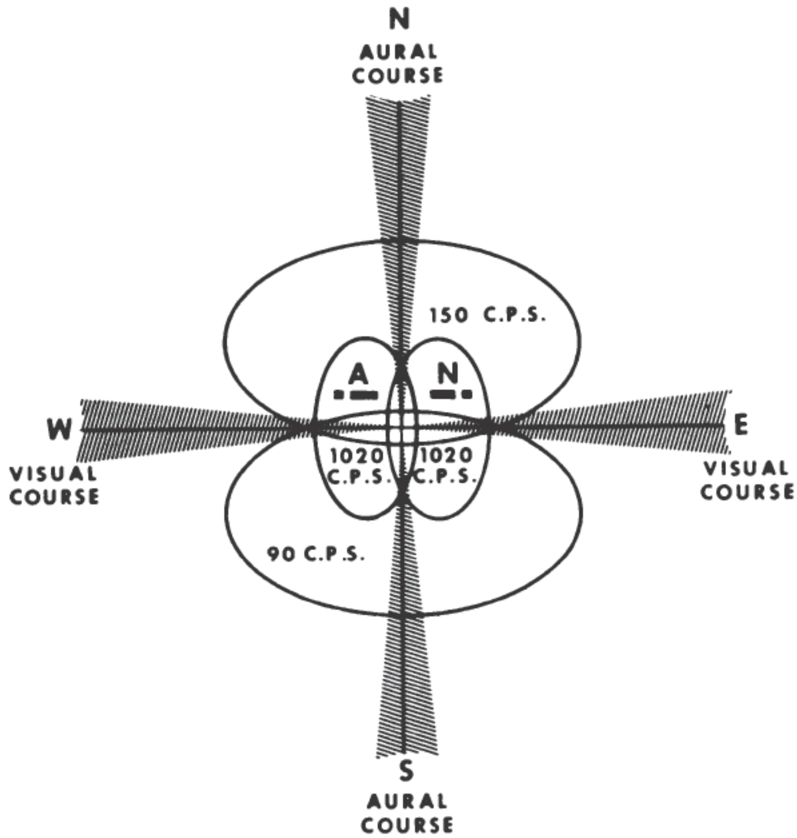


Figure 8–3.—Radiation patterns and courses of the VAR system.

The aural courses are formed in the overlapping areas of A and N signals and are radiated by the same general method employed in the low-frequency range. The antenna array contains three horizontal loops for the visual system and two additional loops for the aural signals. The center antenna serves to radiate the carrier which

combines with both the aural and visual signals to form beat frequencies in the receiving equipment.

The visual courses are defined by the intersection of two oval patterns of radio energy, one containing 90-cycle and the other 150-cycle modulation. The pattern to the north of the visual course is generally called the blue area and that to the south, the yellow area. The visual course is flown by observing the deviation of the vertical pointer of a left-right meter on the instrument panel of the plane. When equal amounts of 90- and 150-cycle energy are received, the pointer is centered and the plane is on the visual course.

The aural signals are received as 1,020-cycle tones interrupted to form the code letters when off the aural course and as a steady tone when on course. When flying the visual course, the aural signals reverse when the plane flies over the range station.

Voice transmissions are made from the VAR facility by modulating the carrier wave radiated from the center antenna. The pilot selects the range signals or the voice transmissions by means of the same type of filter which is employed in reception of the low-frequency range signals. Six channels are used by this facility. These are situated between 108.3 and 110.3 megacycles.

INSTRUMENT LANDING SYSTEM (ILS).—The instrument landing system, one of the facilities of the new federal airways, operates in the VHF portion of the spectrum. The entire system consists of a runway localizer, a glide path signal, and marker beacons for position location.

The localizer equipment produces a radio course alined with the center of an airport runway. As in the visual course of the VAR radio range, the on course signal results from equal reception of two signals, one containing 90-cycle modulation and the other containing 150-cycle modulation. On one side of the runway center line the radio receiver develops an output in which 150-cycle tone predominates. This is called the blue sector. On the other side of the center line, 90-cycle output is greater and this area is called the yellow sector.

In the aircraft receiver, the output circuit contains a

balanced rectifier connected to a zero-center microammeter which remains centered as long as equal amounts of the two tones are present. Deviation of the plane to either side of the final approach course results in deviation of the indicator as shown in figure 8–4.

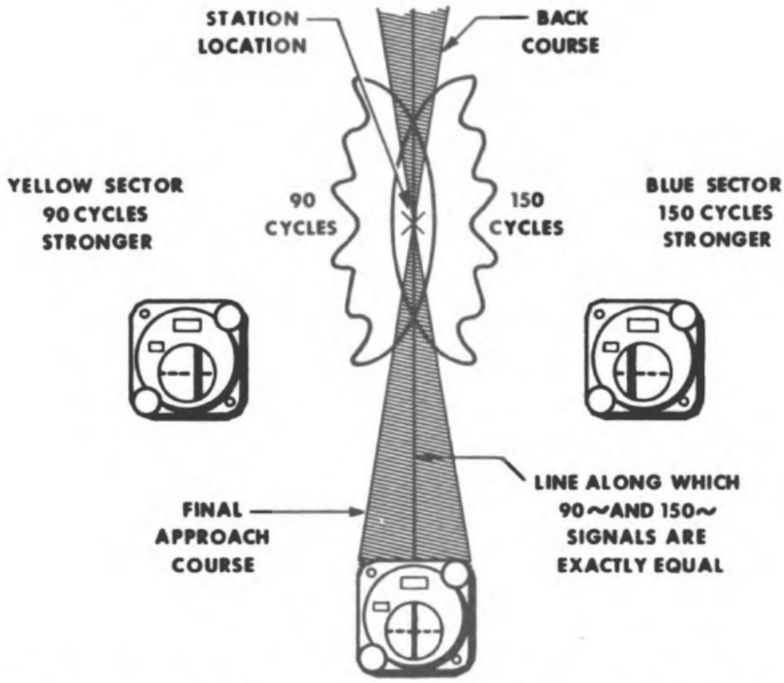


Figure 8–4.—Tone localizer pattern and instrument indications.

The localizer transmitter operates at about 110 megacycles. The transmissions are made from an antenna array containing eight loops situated about 1,500 feet from the end of the runway. Three kinds of transmissions are made. Six of the loops radiate sideband energy only. Sidebands containing 90-cycle modulation and those containing 150-cycle modulation are separated by a sharp null directed along the center line of the runway. Two of the loops radiate the carrier wave containing equal amounts of 90- and 150-cycle tones and this signal is sent along the null separating the sectors. Signals are received in any location, but as indicated in the figure, only along the runway center line are the 90- and 150-cycle tones received in exactly equal amounts.

The glide path is a radio beam which gives vertical guidance to the pilot assisting him in making the correct angle of descent to the runway. Glide path signals are radiated

from two antennas which are driven by a crystal-controlled transmitter operating at about 330 megacycles. The power output is about 25 watts.

One antenna radiates a beam which is very broad in the vertical plane. This beam contains signals modulated by a 90-cycle tone. The other antenna emits signals modulated at 150 cycles in many lobes which are very narrow in the vertical plane. The glide path is an area of intersection between the broad 90-cycle lobe and the lowest of the 150-cycle lobes. In this area, which is a conical beam, the receiver develops equal amounts of 90-cycle and 150-cycle signals in the output. The beam is inclined about 2.5 degrees with the horizontal.

The glide path receiver is a crystal-controlled superheterodyne which is powered entirely from a 28-volt, d-c source and requires no high-voltage power. The receiver audio output containing the 90- and 150-cycle tones is filtered and the two signals are rectified separately. The resulting direct current is applied to a zero-center microammeter which indicates by means of a horizontal pointer. (The localizer and glide path indicators are mounted on the same instrument. However, in many military installations the glide path equipment is not employed.) The pilot flies the glide path by keeping the horizontal pointer in the center of the dial.

Marker beacons and compass locators are used in connection with the instrument landing system. The markers are signals which indicate the position of the plane along the approach to the runway and are similar to the Z-marker equipment employed in low-frequency range stations. Two markers are used in each installation. The location of each is identified both by tone modulation and by a signal lamp. The outer marker is located about 4.5 miles from the end of the runway. The signal is modulated by a 400-cycle tone and is keyed in long dashes (two dashes per second). The inner marker, located at a distance of 3,500 feet, is modulated at 1,300 cycles per second and is keyed with alternate dots and dashes.

Compass locators are low-power nondirectional beacons which provide signals for automatic direction finding equip-

ment. They operate between 200 to 400 kilocycles and are located near the marker beacon transmitters. The locator near the outer marker is coded with the first two letters of the localizer transmitter identification letters and the locator near the inner marker employs the last two letters of the call signal.

THE OMNIDIRECTIONAL RANGE (VOR).—As the name implies, the omnidirectional, or all-directional, range station provides the pilot with courses from any point in its service area. It produces an unlimited number of radials, any one of which is a radio path to the station. Operation is in the VHF portion of the radio spectrum with the result that interference from atmospheric and precipitation static is negligible. The navigational information is presented in a visual form, is constantly available, and is provided regardless of the position of the aircraft in the service area.

The basic provision of the VOR facility is a means of determining the angular position, or azimuth, of an aircraft with respect to the station. This measurement is made in the airborne receiver which determines the phase difference of two 30-cycle tones derived from two signals radiated from the range station transmitting antenna array. One signal, called the REFERENCE PHASE, is broadcast in a nondirectional radiation pattern. At all points on a circle having the station as a center, corresponding parts of this 30-cycle modulation occur at exactly the same time. Since the phase of this signal is independent of azimuth, it is used as a reference for comparison with another 30-cycle variation derived from a signal called the VARIABLE PHASE.

The variable phase signal is radiated in a figure-of-eight pattern which revolves about the transmitting antenna in a way somewhat similar to a rotating searchlight beam. The pattern consists of a positive and a negative lobe which turn together at 1,800 r. p. m., or 30 revolutions per second. As a result of the rotation of the pattern, the signal induced in the receiver is amplitude modulated with 30-cycle variations. The receiver develops this tone and compares it with the references signal. The amount of phase difference between the two depends on the location of the plane with respect to

the station. A phase measuring circuit in the receiver enables the pilot to determine the magnetic bearing and also to select and fly a range course to the station on any desired bearing.

As shown in figure 8–5, the VOR transmitter is modulated both by a 9.96-kc. subcarrier and by an additional component either of voice or the station identification code characters. The subcarrier is frequency modulated at 30-c. p. s. and is generated by a notched tone wheel rotating in a magnetic field. The purpose of the subcarrier is to provide a means for separating the 30-cycle tone of the reference phase from the variable tone of the same frequency.

The modulated output of the transmitter is applied both to a modulation eliminator and to the center loop antenna of a five-element array. There it is radiated to form the reference phase signal. The modulation eliminator is a clipper which removes the amplitude modulation from the carrier. The unmodulated output is fed to a capacity goniometer which serves as a mechanical sideband generator. The goniometer is a motor-driven, double capacitor in which one set of stator plates is displaced 90 degrees from the other set. The rotor plates to which the r-f signal is applied are driven at 1,800 r. p. m., or 30 revolutions per second. Two outputs are derived, one from each set of stator plates. These two signals contain modulation components (30 c. p. s.) which differ in phase by 90 degrees because of the capacitor plate relationship. One output is fed to one pair of diagonally opposite loop antennas and the other is fed to the remaining pair of loops in the square array. Each pair of corner antennas produces a figure-eight radiation pattern. These two patterns are displaced from each other by 90 degrees both in space and in time phase. The resultant pattern is the sum of the two crossed figure-eight patterns and consists of the rotating field described above.

Figure 8–5 shows in simplified form the essential elements of the receiver which enable the pilot to select and fly a range course to the omnidirectional station. In the VOR transmitting system, the reference and the variable signals are in phase along the zero-degree radial (bearing due south of the station). The phase difference between the signals

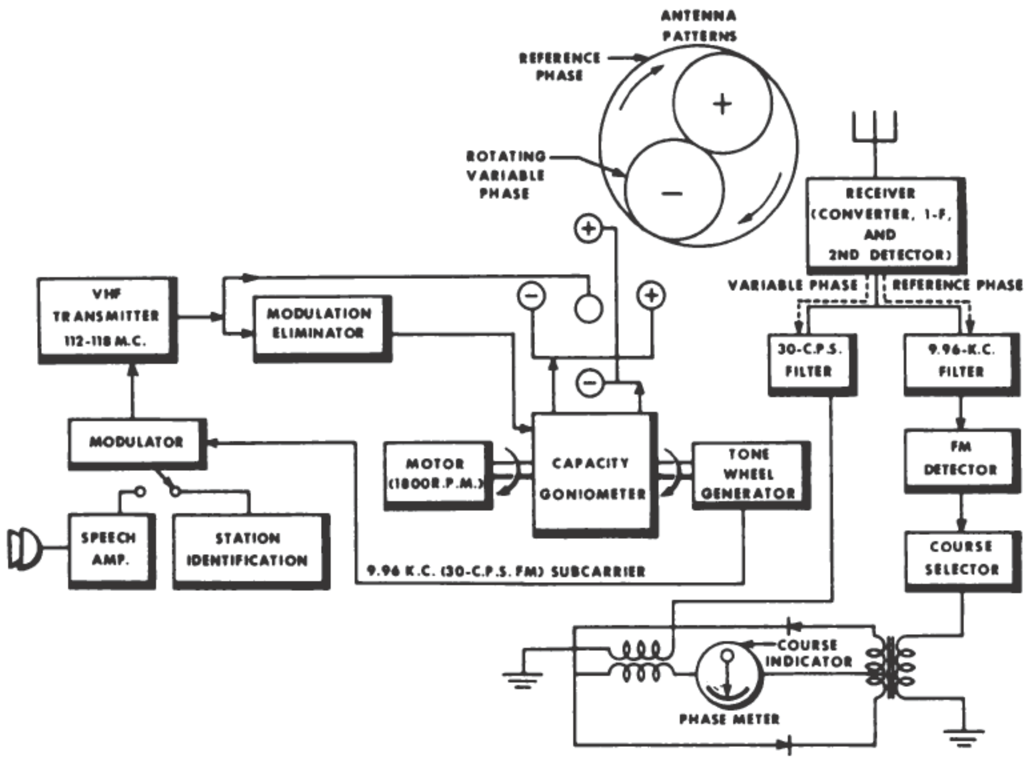


Figure 8–5.—Omnirange system fundamentals.

changes proportionately with the change in bearing to the station. The airborne receiver measures the magnetic bearing of the range station by the following general method:

1. The reference and variable signals are received and separated.
2. The two signals are then applied to a phase bridge containing a zero-center meter (the vertical pointer instrument used with the ILS localizer beam).
3. The reference signal is applied through a phase shifter, or course selector, equipped with a dial calibrated in degrees from 0 to 360.
4. The reference signal is shifted (in phase) by adjustment of the calibrated course selector until the phase bridge is brought to a zero indication. The amount of phase shift required to zero the bridge is proportional to the magnetic bearing of the range station.

To fly a given course to the station, the pilot sets the phase shifter until the calibrated dial reads the desired bearing. With this setting the reference signal is phased so that

a balanced condition of the course indicator needle is shown as long as the plane is on the selected radial. To follow the radial to the station, the pilot flies so as to keep the vertical needle of the course indicator in the center position.

As indicated in figure 8–5, the receiver is an ordinary superheterodyne through the second detector. Following the second detector, filter circuits separate the 9,960-c. p. s. subcarrier and the variable phase 30-cycle signals. The f-m subcarrier is then applied to an f-m detector which recovers the 30-cycle reference voltage. After passing through the phase shifter (course selector), the reference voltage is combined with the variable signal in the phase meter circuit.

The phase meter is a bridge which is balanced (indicated by a center position of the course indicator) when the two 30-cycle variations applied to it differ in phase by 90 degrees. At this relation, the vector sum of the voltages in the upper half of the circuit is equal to the vector sum of those in the lower half. The two sums are converted into d. c. by rectifiers and applied to the zero-center instrument with opposite polarity.

The phase shifter contains two transformer windings mounted at right angles, and these two are fed with two components of the reference signal. A third winding rotates inside the other two coils, and a voltage is induced in it with a phase angle which depends on the rotor position with respect to the two primaries. The rotor coil is attached to a counter-type dial which is calibrated in degrees to indicate the magnetic bearing to the range station. A manually adjustable set knob is used to position the rotor for the desired magnetic course.

The vertical pointer of the course indicator also shows a centered position when the aircraft is flying on the reciprocal radial which is 180 degrees from the selected course. (This results from the fact that these are two positions of the phase shifter which will balance the bridge circuit.) A TO–FROM INDICATOR is included in the course selector instrument which enables the pilot to know when he is flying the reciprocal of the radial shown on the course dial. This indicator reads TO when the aircraft is on the selected radial and FROM

when it is on the reciprocal of this radial. For example, in flying a 90-degree radial to the station, the course indicator needle remains centered and the To–From indicator reads TO while the plane is approaching the station from the west. After passing over the station while maintaining the same heading, the course needle remains centered but the To–From indicator then reads FROM.

DISTANCE MEASURING EQUIPMENT (DME).—Eventually each omnirange station will be equipped with distance measuring equipment (DME). By means of this facility, airborne units will provide the pilot with constant visual indications of his distance from the range station. The combined omni and DME information provide all the primary data required for point-to-point air navigation. These data consist of exact knowledge of the plane's distance from and direction to one or more points.

DME units operate similarly to IFF and radar beacons. The airborne unit, called the INTERROGATOR, transmits a train of short pulses which are received by the ground unit, called a TRANSPONDOR. After reception of the challenging pulses, the ground station using suitable circuits shapes them into trigger impulses which modulate a pulse transmitter to send a reply to the aircraft. Upon reception by the interrogator, the elapsed time between the challenge and the reply is measured. This interval is a measure of the distance separating the aircraft and the transpondor beacon.

The challenge sent by the aircraft consists of spaced pulses in the 960–990 megacycle band. The ground station equipment is set to accept only those signals which have the correct spacing and which are on the correct frequency. The frequency and spacing characteristics define a challenge channel. The reply consists of a train of r-f pulses in the 1,185–1,215 megacycle band. The combination of the challenge and reply channels is called an OPERATING CHANNEL. Up to 50 aircraft can use the same ground beacon to obtain DME information without interference.

The airborne unit, shown in block diagram form in figure 8–6, consists essentially of timing circuits, search and tracking circuits, and the indicator meter.

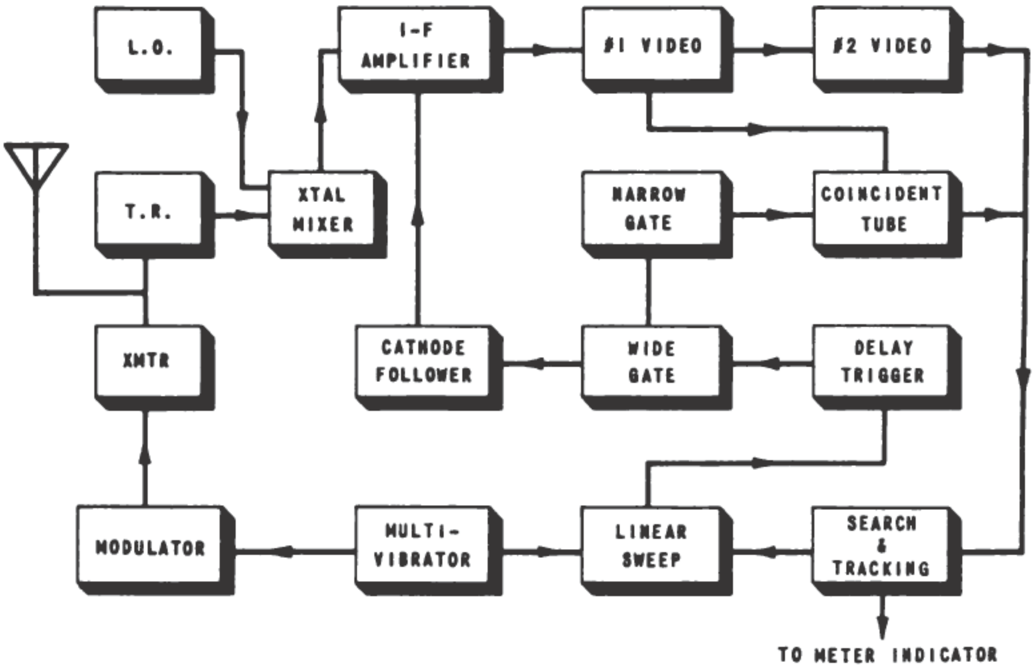


Figure 8–6.—Block diagram of airborne DME unit.

The TIMING CIRCUITS measure the time interval between the transmission of a challenging pulse from the transmitter and the reception of the corresponding reply pulses. As in radar operation, this time value is a measure of the distance separating the plane and the beacon.

The SEARCH CIRCUITS operate by causing the equipment to seek out a reply after each challenge. Briefly, the search function is as follows: the receiver is triggered on by gating circuits and operates for a very brief period of time after each challenge. The gate pulse which activates the receiver is separated from the challenge by an interval of time delay, *T*. Interval *T* is made to vary between 0 and 1,200 microseconds, corresponding to a range of distances from zero to approximately 112 miles. The receiver goes into operation after each challenge but delayed by a different interval of time after each emitted signal. The receiver, then, can accept beacon replies only when the delay time, *T*, is equal to the time required for a challenge signal to reach the beacon and the reply to return. When the time delay is such that the beacon reply is received, the search circuits are disconnected and the tracking operation begins in which the

receiver holds the signal which it has found. When this occurs, the distance of the beacon is indicated on the dial of the indicator. This is accomplished by measuring the delay time, T. The value of T is controlled by a voltage to which it is directly proportional. When the search circuits have discovered a reply, the control voltage is applied to a voltmeter which is calibrated in miles.

The TRACKING CIRCUITS of the equipment adjust the time of operation of the receiver so that the received beacon reply is accepted even though the distance between the plane and ground station is constantly changing. In tracking operation the receiver is controlled by the action of two gating impulses. These are the wide gate (20 microseconds) and the narrow gate (10 microseconds). A signal received in the wide gate increases the delay time and one during the narrow gate decreases it. Thus the two control gates effectively bracket the reply signal and keep the receiver operating at the time when the reply pulses arrive. As a result, the distance meter continually indicates the number of miles between the plane and the beacon.

The automatic search circuits can be started again when the pilot wishes to track on another beacon. If the new beacon is more distant than the first, a release switch is pressed which causes the delay to increase and the search circuits begin operating to seek out the delay time corresponding to the station. If the alternative beacon is nearer than the first, a zero switch is pressed which causes the delay time to start again from zero before resuming search operation.

A pilot lamp near the DME meter indicates the presence or absence of a signal, and is burning if no signals are present. The beacon transmissions are gap-coded; that is, the replies are arranged so that intervening spaces form the Morse code letters assigned to identify the beacon. When the signals are being received, the pilot lamp flashes on and off, giving the beacon code identifier. When the plane is at a distance beyond the operating range of the beacon, the light burns continuously to warn the pilot that the meter reading

is no longer the true distance but is the distance at which the signal was last received.

Course line computer.—The usefulness of the information provided by VOR stations equipped with distance measuring equipment can be greatly extended by means of a device called a course line computer. The computer makes it possible to fly a constantly indicated course between any two points within the reception range of a VOR–DME station. The pilot does not need to proceed directly to or from the range station. He merely sets the desired course into the computer and the instrument uses the VOR–DME signals to guide him.

A part of the basic data required by the computer concerns the exact location of the desired destination with respect to the range station. The location is expressed by two values called R and theta as shown in (A) of figure 8–7.

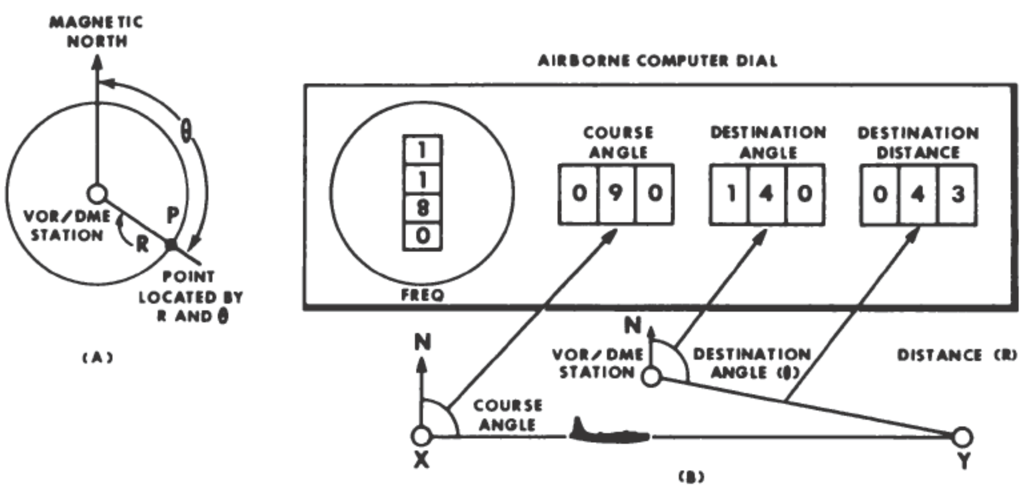


Figure 8–7.—Course line computer settings.

The distance of any unknown point, P, is called R since it can be visualized as a radius of a circle having the ground station as a center. The magnetic bearing (theta) of the point from the station is an angle whose value determines the position of the point on the circumference of the circle.

The additional data required by the computer is indicated in (B) of figure 8–7. There a navigational problem is illustrated in which it is desired to fly from point X to

point Y. The pilot sets up the course by dialing the R and theta values of the destination into the computer. He then dials the course angle (90 degrees in the example) or magnetic bearing of the destination from the starting point. The frequency dial of the equipment is set to the assigned frequency of the range station.

While the plane is en route over the selected course, the computer calculates instantly and continually the distance from the VOR station that will place the aircraft on the line XY. At the same time it takes the measured distance from the station provided by the airborne DME unit and compares this value with the calculated distance. This gives an indication of any deviation from the course line, and this information is shown in the vertical needle of the deviation meter. As long as the needle is centered, the plane is flying the selected course.

The computer also calculates continuously the distance of the aircraft from the destination and indicates the result on an indicator dial as "destination distance." When the distance meter reads zero and the course deviation is centered, the pilot knows he is over the destination.

In some computers, the course information is not presented by means of dials but is given in pictorial form. In these, the image of a small airplane is projected onto the surface of a chart or map. The progress of the aircraft is represented by the movement of the image over the chart, and the pilot watches this simulated motion to determine his position and progress along the selected course.

AIRBORNE EQUIPMENT

AN/ARN–14 Radio Receivers

The AN/ARN–14 series consists of five radio receivers which are designed to provide the pilot or other members of the aircrew with all of the radio aids to navigation now available in the very high-frequency range. Three of the receivers of the series are used in Navy installations. These are the AN/ARN–14A (Bendix), the AN/ARN–14D (Bendix), and the AN/ARN–14E (Collins). The reception range of

these receivers includes both military and commerical communication channels, omnidirectional range channels, tone localizer service, and visual-aural range (VAR) service.

PURPOSE OF THE EQUIPMENT.—Each of the AN/ARN–14 units is an airborne navigation receiver equipped with three indicators to supply navigational data. The receivers also contain provision for audio output. The equipment is designed for the following functions:

1. Reception of VHF omnirange signals with visual display of on-course information.
2. Indication of the magnetic bearing of the omnirange station from the aircraft.
3. Indication of the magnetic heading of the aircraft.
4. Indication of the angular difference between a selected course and the magnetic heading of the aircraft.
5. Reception of tone localizer signals with a visual display of this information on the course indicator instrument.
6. Indication of reciprocal courses by means of a To–From indicator.
7. Indication by means of flag alarm indicators when the signal level is unsatisfactory for localizer or omnirange operation.
8. Reception of voice facilities on the communication channels and a voice transmission superimposed on the navigation signals in the localizer and the omnirange bands.

FREQUENCY RANGE.—The frequency range covered by all AN/ARN–14 receivers extends from 108 to 135.9 megacycles. Two hundred and eighty crystal-controlled channels assigned for navigational aids and voice communications are provided. These channels are spaced 100 kilocycles apart. The AN/ARN–14A receiver is wired for the following types of operation in the frequency ranges shown:

Frequency in megacycles	*Use*
108–110.9	Tone localizer
111–111.9	Weather broadcasts
112–117.9	Omnirange operation
118–121.9	Tower communication (voice)
122–135.9	Communications (voice)

The AN/ARN-14D and AN/ARN-14E receivers cover substantially the same frequency ranges except that tone localizer signals are received on odd tenths of megacycles between 108.1 and 111.9 mc. These receivers are wired for reception of omnirange stations located at airways terminals (TVOR stations) on even tenths of megacycles between 108 and 111.8 mc.

Description of Major Units

The major units of an AN/ARN-14 installation consist of three indicators, a radio receiver, a control panel, a dynamotor, an antenna, and two mountings. One of the mountings is associated with the receiver and one with the dynamotor.

COURSE INDICATORS.—Course Indicator ID-249A/ARN is intended primarily for use by the pilot. It consists of (1) a To-From indicator, (2) flag alarms, (3) a course marker, (4) a marker beacon indicator, (5) a horizontal pointer used for glide path operation—this is usually inactive in Navy installations, (6) a relative heading pointer, (7) a vertical pointer for range and localizer operation, and (8) a radial selector knob. The instrument is illustrated in (A) of figure 8-8.

The radial selector knob marked SET is rotated to select a desired radial which is indicated through the course marker window. The To-From indicator is used only with omnidirectional range service. It differentiates between the selected radial and the reciprocal radial, and indicates TO when the aircraft is on or near the selected radial and FROM when the aircraft is on or near the reciprocal. The relative heading pointer indicates the heading of the aircraft with respect to the radial which is shown on the course marker. It operates in conjunction with signals from the aircraft compass system. The vertical pointer is used with the range and localizer services. It maintains a center position when on course and deviates when off course. The vertical flag alarm indicates OFF when the received signal strength is too weak for use, and the flag disappears

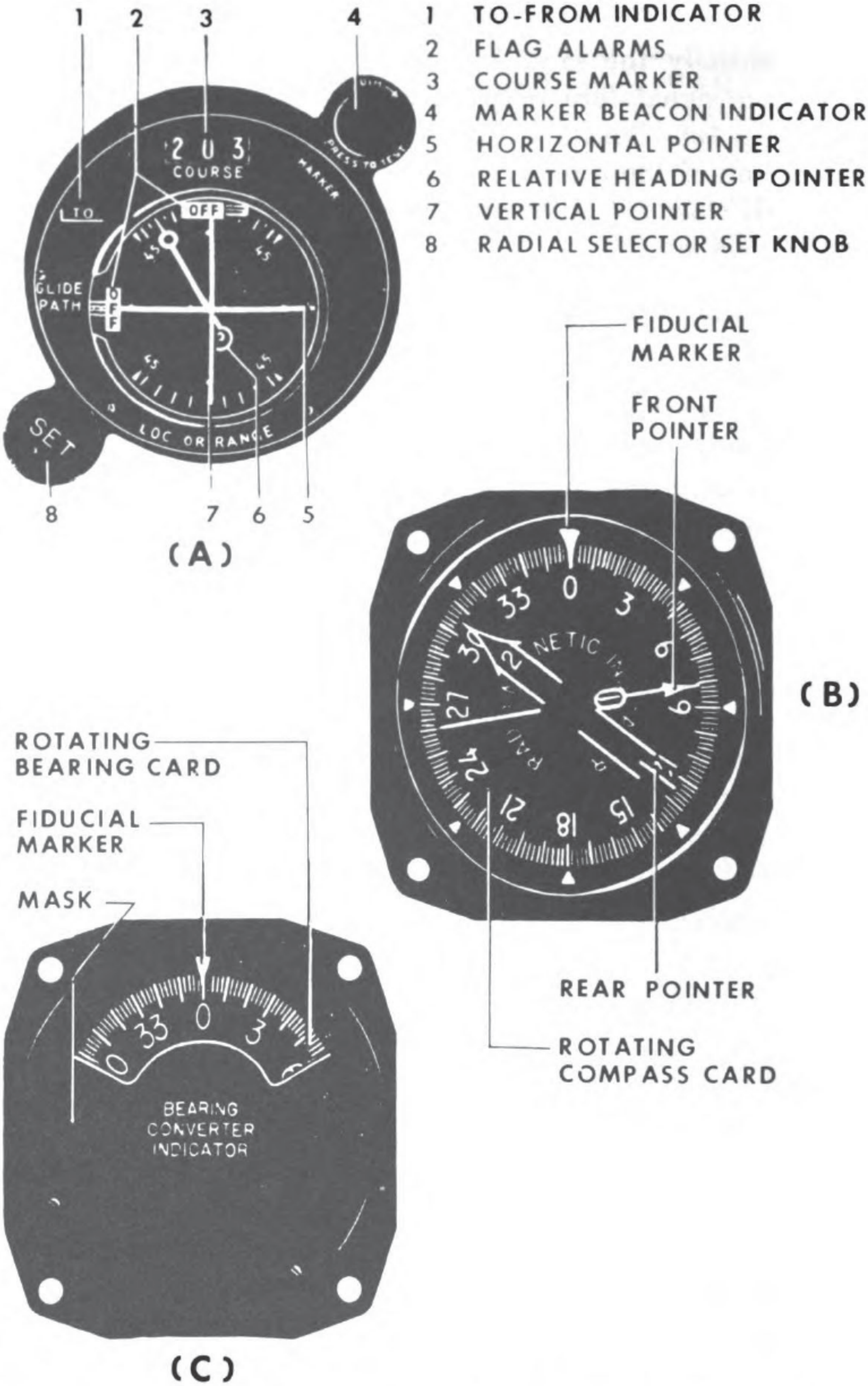


Figure 8-8.—AN/ARN-14 instruments. (A) Course Indicator ID-249A/ARN; (B) Course Indicator ID-250/ARN; (C) Radio Indicator Control ID-251/ARN.

from view when the received signal strength is sufficient for use.

Course Indicator ID–250/ARN, shown in (B) of figure 8–8, is also called the Radio Magnetic Indicator or RMI. It is located either in the navigator's compartment or in the cockpit. The rotating compass card is controlled by the remote indicating magnetic compass. The card rotates so that the magnetic heading of the aircraft is indicated against the fiducial marker at the top of the instrument face. The 0 degree mark on the rotating card always represents magnetic north and the fiducial marker represents the heading of the aircraft. The figure read on the rotating compass card at the pointed end of the double-barred pointer is the maanetic bearing of the omnidirection stgtion as measured from magnetic north, or the magnetic heading to fly to reach the station. The front pointer is used in installations where another source of direction-finding information is available so that two different stations may be located. Ordinarily, in a single receiver installation, the rotors and stators of the motors which drive the pointers are connected in parallel so that both needles rotate together and indicate the same bearing.

Radio Indicator Control ID–251/ARN, shown in (C) of figure 8–8, provides a continuous indication of the magnetic bearing of the omnidirectional range station to which the receiver is tuned. It consists of a fiducial marker and a rotating bearing card which follows the azimuth position of the aircraft with respect to the VOR station. When the aircraft is in the effective receiving range of the VOR station and the receiver is tuned to the station frequency, the fiducial marker points to the radial on which the aircraft is required to fly to reach the station. Primarily, the unit is used for electrically combining the magnetic heading information from a magnetic compass with the directional information from the radio receiver to provide bearing indications for the operation of Course Indicator ID–250/ARN. Hence, the unit does not need to be observed visually and is usually located at a remote point in the aircraft.

Receiver.—All the AN/ARN–14 receivers cover the

frequency range from 108 through 135.9 mc., and provide 280 channels spaced 100 kilocycles apart. In the AN/ARN–14A and AN/ARN–14D units (Bendix), a triple conversion superheterodyne system is employed using three crystal-controlled oscillators. Two of the local oscillators are controlled by 34 crystals and, in conjunction with the frequency selector circuits, provide crystal operation on each of the 280 channels in the receiver input. The other local oscillator is controlled by a separate crystal aud generates a signal which is mixed with the second intermediate-frequency signal to produce a final i-f voltage. The AN/ARN–14E (Collins) receiver employs a double-conversion superheterodyne with crystal control to convert the received signals to a low-frequency value for demodulation.

The portion of the demodulated signals which contains voice modulation and station identification is fed to the audio channel where it is passed through a squelch circuit, a noise limiter, an audio amplifier, and an audio output stage. The final audio output is then applied to the aircraft interphone system. A volume knob on the control panel is used to determine the audio level. The portion of the signal which contains the omnirange and other navigational information is fed to the part of the receiver called the instrumentation circuits.

Control panel.—Remote control of the AN/ARN–14 equipment is provided by a control panel which includes an ON-OFF switch, a volume control knob, two frequency selector knobs (whole megacycle and tenth megacycle), and a frequency indicator. The frequency indicator is a window through which the digits of the selected frequency appear. Since all frequencies covered by the receiver have 1 as the first digit, this number is fixed underneath the indicator window. The whole megacycle knob changes the next two digits from 08 to 35. The tenth megacycle selector knob changes the last digit from 0 to .9 in steps of tenth-megacycles.

Dynamotor.—The electronic circuits of the equipment are supplied with d-c voltage by a dynamotor. In Navy installations, Dynamotor DY–84/ARN–14A is used. The

input voltage is 26.5 volts, and the d-c output potential of the generator section is 235 volts. To this output is added the 26.5-volt input in a series connection to give a total output of 261.5 volts. The normal output current of the dynamotor is 150 milliamperes. In addition to the 26.5-volt primary source, the aircraft's power system supplies alternating current at 26 volts and 400 cycles per second for operation of the synchros in the indicator circuit.

ANTENNA.—The antenna, (AT–172/ARN–14), is of the deerhorn type and is designed to receive horizontally polarized waves in the frequency range for which the receiver is designed. The antenna is connected to the receiver with 52-ohm coaxial cable (RG–8U or equivalent).

Description of Receiver Operation

The receiver which is the principal part of the ARN–14 equipment is shown in block diagram form in figure 8–9. It can be considered as being divided into three major sections. These are the radio-frequency, the audio-frequency, and the instrumentation sections. All signals pass through the r-f section and are demodulated in the second detector. Following this stage, voice and station identification signals are applied to the audio section and finally to the interphone system. The navigational information derived from the detector is conveyed to the instrumentation circuits.

Signals from the antenna are fed through coaxial cable to the receiver which, in the model shown, is a double conversion superheterodyne. After conversion to relatively low frequencies for amplification, all signals are demodulated in a diode detector. Four types of signals are recovered from the carrier. These are as follows:

1. Audio voice communications and station identifications.
2. A 30-cycle variable phase signal used in omnirange operation.
3. A 9,960-cycle subcarrier which is frequency modulated with 30-cycle variations comprising the reference phase signals for omnirange operation.

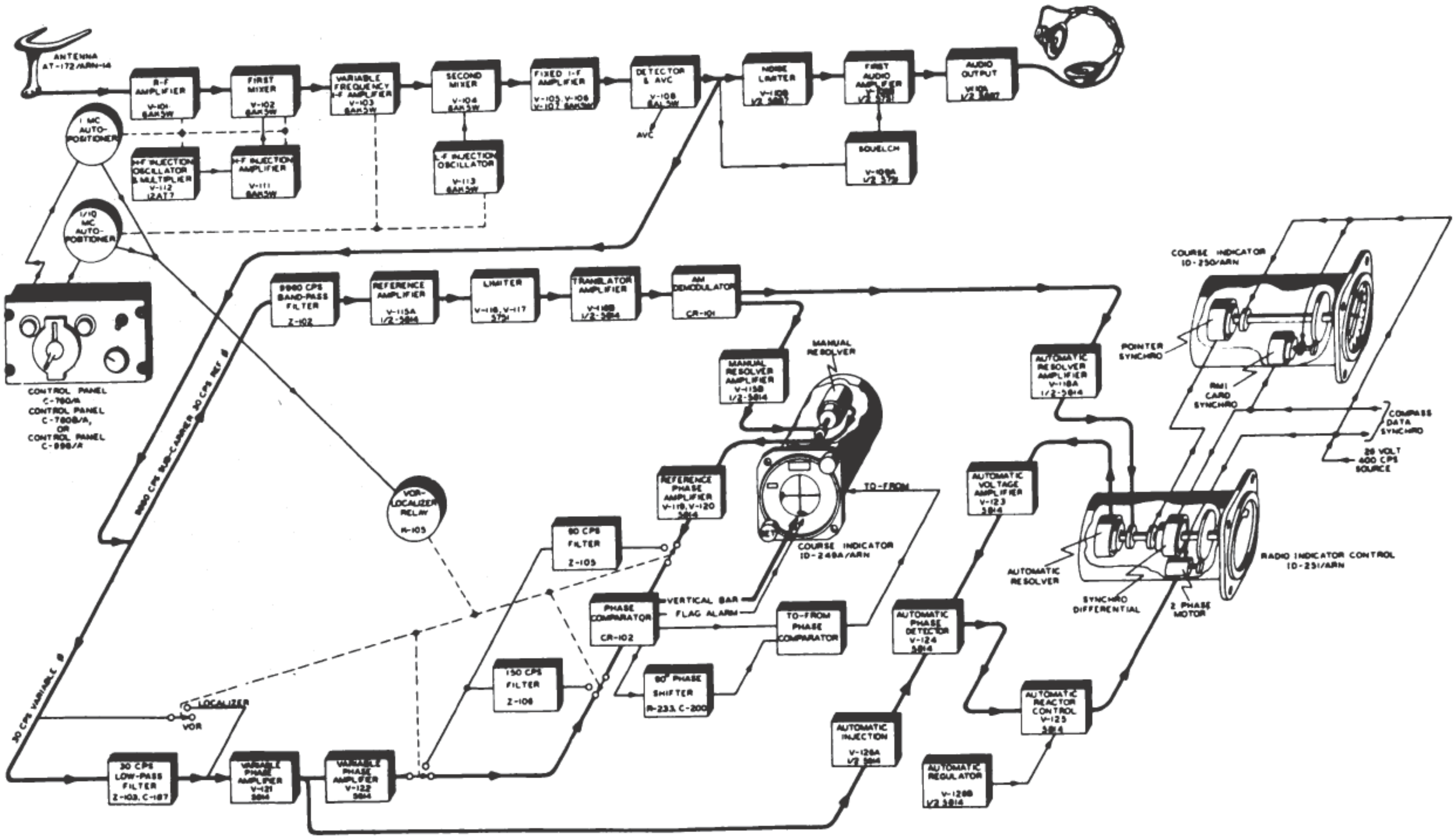


Figure 8-9.—Block diagram of Receiver R-252A/ARN-14 (Collins).

4. A mixture of 90- and 150-cycle voltages received from tone localizer transmitters.

The last three of these types of signals are applied to the instrumentation section and the first type is applied to the audio circuits.

R-F AND AUDIO SECTIONS.—The receiver R–252A/ARN–14 employs one stage of r-f amplification. The grid and plate tank circuits of the r-f amplifier, V101, pass a two-megacycle band and cover the frequency range of 108 to 135.9 megacycles in 14 steps. Following the r-f stage is the first mixer, V102, into which is fed both the incoming signals and the injection signal from a three-stage exciter. The exciter consists of a crystal-controlled oscillator-multiplier, V112, and an amplifier, V111. When the signals are mixed with the injection voltage, an intermediate frequency is produced in the range of 19.45 to 21.35 megacycles. This component is amplified in a variable i-f amplifier, V103, and then applied to the second mixer. The injection voltage for the second conversion is derived from a crystal oscillator-multiplier, V113. The second mixing process produces i-f signals at a fixed frequency of 3.15 megacycles. After passing through three i-f amplifiers, the signal is detected in V108, a 6AL5W tube connected in a detector-AVC circuit.

The AVC system maintains the output of the receiver substantially constant over a wide range of incoming signal frequencies. A series noise limiter of the peak clipping type is employed to prevent sharp noise peaks and random voltage pulses from reaching the grid of the first audio amplifier tube. A squelch circuit biases the first audio grid to cutoff when no signal is being received and relaxes the audio grid voltage to allow the tube to operate only when a carrier signal is present in the receiver input.

INSTRUMENTATION SECTION.—This section is divided into three parts. These are the REFERENCE PHASE, the VARIABLE PHASE, and the AUTOMATIC CIRCUITS. The reference phase circuit processes the 9,960-cycle subcarrier which is frequency modulated with the 30-cycle reference voltage. The variable phase circuit is concerned with the 30-cycle signal obtained

from the detector. The automatic circuit accepts both the reference and the variable voltages.

The reference phase circuit receives the f-m subcarrier from the second detector through a capacitor which blocks the 30-cycle variable phase signal but allows the higher-frequency subcarrier to pass. The latter voltage is amplified in V115–A which contains a resonant band-pass filter circuit in the input. After amplification, the reference signal passes through two limiter stages each consisting of a twin triode connected as a combination of a cathode follower and a grounded grid amplifier. These convert the subcarrier into a series of square waves which are then applied to the translator amplifier. This circuit contains a parallel-resonant tuning circuit with a resonant frequency slightly higher than 9,960 c. p. s. so that the input signal falls on the slope of the resonance curve. The output of the amplifier contains an amplitude-modulated wave which is then detected in a bridge rectifier circuit which develops the 30-cycle reference voltage. This signal is applied to a manual resolver in the pilot's indicator. The resolver is a phase shifter used by the pilot to set the desired omni course. After being shifted in phase and amplified, the reference voltage is then applied to the phase comparator, C102, which is a phase bridge in which the reference and variable signals are compared in phase.

The variable phase circuit accepts the 30-cycle signal from the detector through a filter, amplifies it in two stages of amplification and finally applies it to the phase comparator. There it is compared with the reference voltage in a double bridge rectifier circuit. The cross pointer needle of Course Indicator ID–249A/ARN is positioned by the combined output voltages of the comparator bridge; and this indicator remains centered when the two signals differ in phase by 90 degrees.

The automatic circuit accepts a portion of the reference signal obtained from the translator, C101, and applies the signal to an automatic resolver, or automatic phase shifter. The variable signal is also applied to the automatic circuit in phase detector V124. The automatic resolver, operating with information from this circuit, shifts the phase of the

reference signal so that it is always 90 degrees removed from the variable signal. The magnitude of the phase shift necessary to maintain this relationship is used as a means of operating Radio Indicator Control ID–251/ARN. This instrument in turn operates the double-barred pointer of Course Indicator ID–250/ARN to reveal the magnetic bearing of the omnirange station to which the receiver is tuned.

Interpretation of Omnidirectional Receiver Instruments

The use of the omnidirectional range in making an approach to the station together with the typical indications given by the instruments used in omnidirectional receivers is shown in figure 8–10.

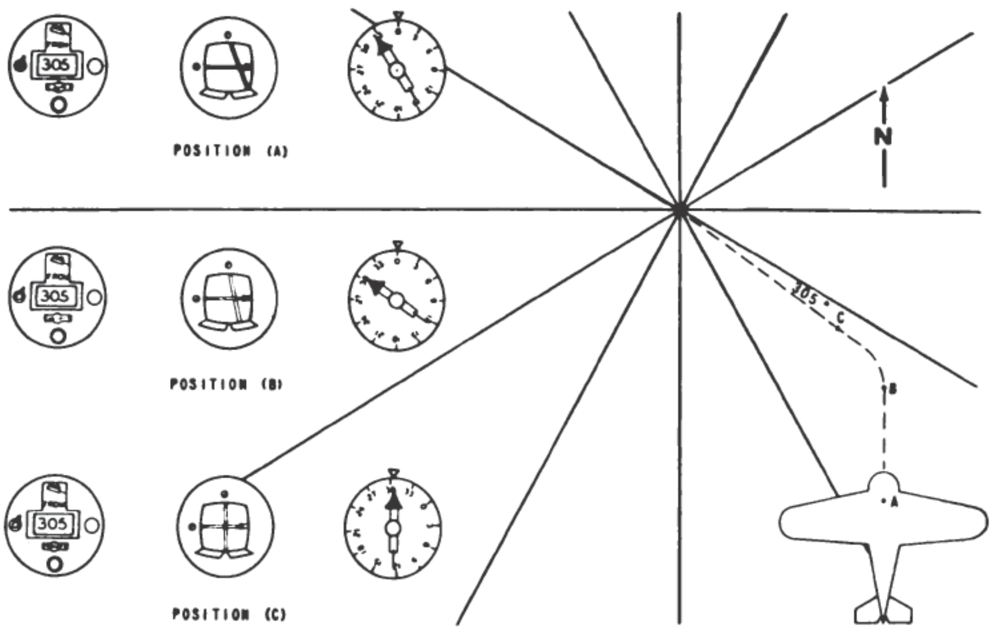


Figure 8–10.—Omnidirectional approach with typical instrument indications.

Starting at position *A*, the needle of the Radio Magnetic Indicator points to the omnistation at the left, the bearing to the station being approximately 320 degrees. The magnetic scale of the RMI reads zero, since the airplane is flying directly north. The pilot, wishing to approach the range station along radial 305, has set the course selector to read 305 TO. The vertical needle of the course indicator reads to the right.

The airplane proceeds north to point *B*; and the needle of the RMI now reads 308 degrees. The azimuth card of the RMI still reads zero since the airplane is still headed due north. The vertical needle of the course indicator has swung in close to the center, showing that the airplane is near the desired track. At this point the pilot starts to turn to the left and arrives at point *C*. There the RMI reads 305 but points straight ahead indicating that the station is directly ahead of the aircraft. The magnetic scale of the RMI reads 305 also. The vertical needle of the course indicator is now centered, showing that the airplane is accurately established on course.

Figure 8–11 shows a plane as having passed over the omnirange station on radial 305, the pilot's intention being to proceed along that track to an intersection with a landing system localizer beam at the terminal field.

At point *D* the pilot's instruments show that he has just passed the range station but that he has slipped a little to the right of his desired track. The RMI needle has reversed and now points back toward the station, which now bears 160

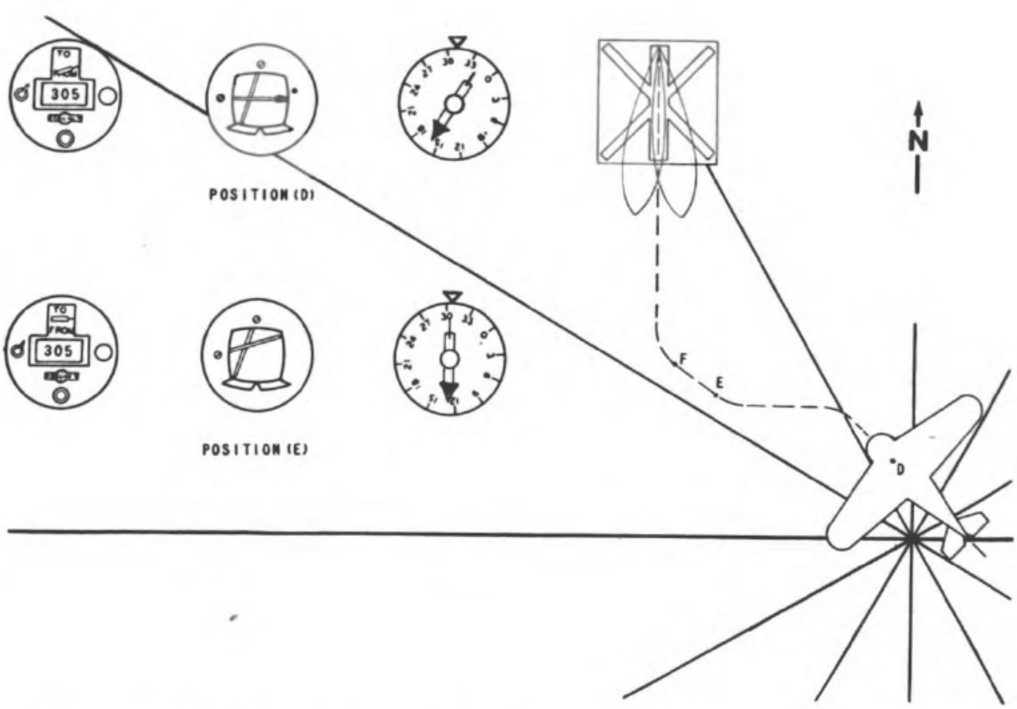


Figure 8–11.—Airport approach with typical instrument indications.

degrees from the plane. The magnetic heading scale of the RMI shows 307 degrees, indicating that the heading is slightly in error to the right. The vertical course indicator needle points to the left of the aircraft. The To–From indicator now shows FROM. The track, or course, selected is now 305 FROM the station.

After readjusting to the correct course, the pilot arrives at point *E*. Here the pilot adjusts the frequency selector of the receiver to pick up the localizer signal of the ILS transmitter at the airport. (A typical value of this frequency is 109.0 megacycles.) At this time the instruments read as follows: The needle of the RMI is now inactive as the receiver has been tuned away from the VOR station frequency. The magnetic scale of the RMI is still in operation and shows the heading of the aircraft to be 305 degrees. The course indicator needle now indicates the position of the localizer beam and is deflected to the left showing that the desired runway line lies in that direction from the aircraft's position.

The pilot proceeds to point *F* where the instrument indications are approximately the same as shown at *E*, except that the course indicator needle has moved in toward center to show that the plane is approaching the desired course line. From this point the pilot is guided by the localizer signal and proceeds with his landing without further reference to the VOR system.

LORAN RECEIVING EQUIPMENT

In this section, aviation loran equipment is introduced by descriptions of two devices, AN/APN–4 and the much newer AN/APN–70. The general principles of the loran system together with the basic types of major components found in airborne loran equipment are illustrated by means of the older unit, which is used here mainly for its value as a concrete example. A block diagram of the newer receiver-indicator and a description of its principal parts are also given. For schematic diagrams of the new unit, the reader is referred to the appropriate *Handbook of Service Instructions*.

Radio Set AN/APN-4

Radio Set AN/APN-4 is an airborne receiver-indicator which is a part of the loran system of long range navigation. As described in chapter 2, the complete loran system contains a chain of ground-based transmitting stations located at intervals along a shoreline. The transmitters radiate pulse-modulated radio signals at various carrier frequencies and pulse recurrence rates. These pulses are received by equipment such as the AN/APN-4 which displays the signals visually on a cathode-ray indicator. The navigator measures the time difference in microseconds between the pulses received from a pair of stations and applies the measured value to a loran chart of the region to obtain a loran line of position. Using the same procedure, a reading from another pair of stations provides a second line of position. The point of intersection of the lines of position indicates the exact location of the aircraft.

The nature of the loran system and the use of the AN/APN-4 equipment are illustrated in figure 8-12. The standard loran transmitters in many cases are arranged in groups, and as many as eight station pairs can be operated at the same carrier frequency. The *A*, or master, station of a pair transmits pulses at a fixed rate of recurrence. A second station, the *B* or slave transmitter, is triggered by the *A* signal and transmits a train of pulses similar to those emitted by the master station. Each *B* pulse is delayed, being emitted after the corresponding *A* pulse by an interval of time equal to a fixed delay plus the time lag representing the distance between the stations. The fixed delay is added to insure that the master pulse will always be received before the corresponding slave pulse.

The pulses are received and displayed on two trace lines as shown in figure 8-12. This method of presentation cancels the fixed time delay (given as 20,000 microseconds as an example in the illustration). The time difference separating the two signals is then determined from the indicator and is represented by the horizontal distance from the master to the slave pulse. The value measured depends principally on

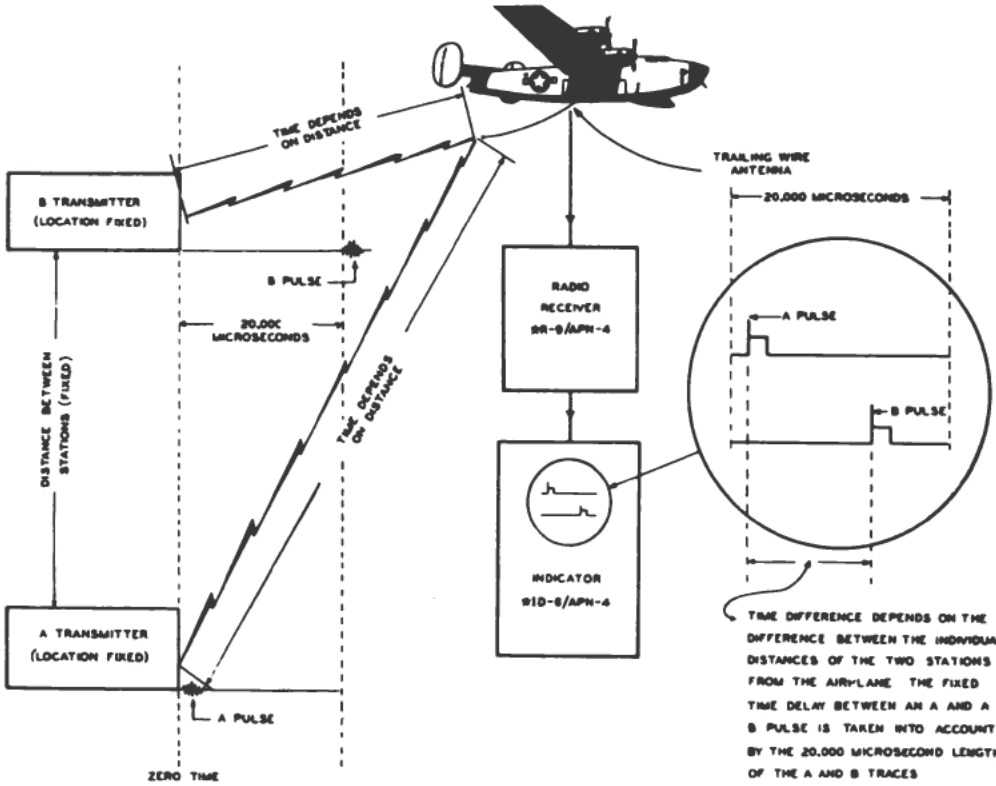


Figure 8–12.—Basic operation of the loran system.

the location of the aircraft with respect to the ground stations and provides the necessary information for obtaining the loran line of position. (The technique used in reading the time value is described briefly in another part of the discussion.)

To receive a given station pair, the operator adjusts the equipment for the following characteristics of the signals:

1. RADIO-FREQUENCY CHANNELS. Standard loran transmitters operate on four channels numbered 1 through 4, corresponding to carrier frequencies of 1,950, 1,850, 1,900, and 1,750 kilocycles, respectively.
2. BASIC PULSE RECURRENCE RATES. Three basic pulse rates are assigned; however, only two of these are used. These are 25 and 33⅓ pulses per second.
3. SPECIFIC PULSE RECURRENCE RATE. There are eight specific pulse rates associated with each basic pulse rate, and each station pair (numbered from 0 through 7) of a group operates with a different specific rate.

To tune in a given station pair, the operator adjusts both the receiver and the indicator of the AN/APN–4 set. The receiver is switched to the r-f channel on which the desired signals are radiated. The indicator controls are set for basic and specific rates so that the sweep lines are formed in exact synchronism with the occurrence of the desired pulses. When synchronized with the indicator sweep, these signals remain stationary and other signals on the same carrier frequency (but with different pulse rates) slip rapidly across the screen and are ignored.

Major Units of the AN/APN–4 Equipment

The equipment consists principally of a receiver and an indicator. These are illustrated in figure 8–13. The receiver shown in (A) of the figure is the R–9A/APN–4 model. The indicator illustrated in (B) is the ID–6B/APN–4.

The receiver front panel contains four switches, several connectors, and a pilot light. The operating controls include a four-position switch for selecting the r-f operating channel. The numbers correspond to the first digit of the loran identification symbol assigned to the station pair.

The remaining switches control the primary power, a filter which can be inserted into the receiver circuit, and a line voltage selector for operation on either 115 or 80 volts.

The two connectors at the lower right are used to attach the receiver to the indicator and to the primary power source. Three numbered coaxial connectors at the upper left are provided for connections to the indicator, and a fourth connector is used for the antenna lead.

The larger unit is the indicator which consists of the cathode-ray oscilloscope and various timing and sweep circuits associated with it. Two small knobs at the upper left control the focus and the intensity, or brilliance, of the display. The toggle switch at the upper right introduces small changes in the frequency of a crystal oscillator to move the loran pulses displayed to the left or right on the indicator screen. Below it is the crystal frequency control knob by means of which the sweep in the C–R tube is brought into exact synchronism with the incoming pulses

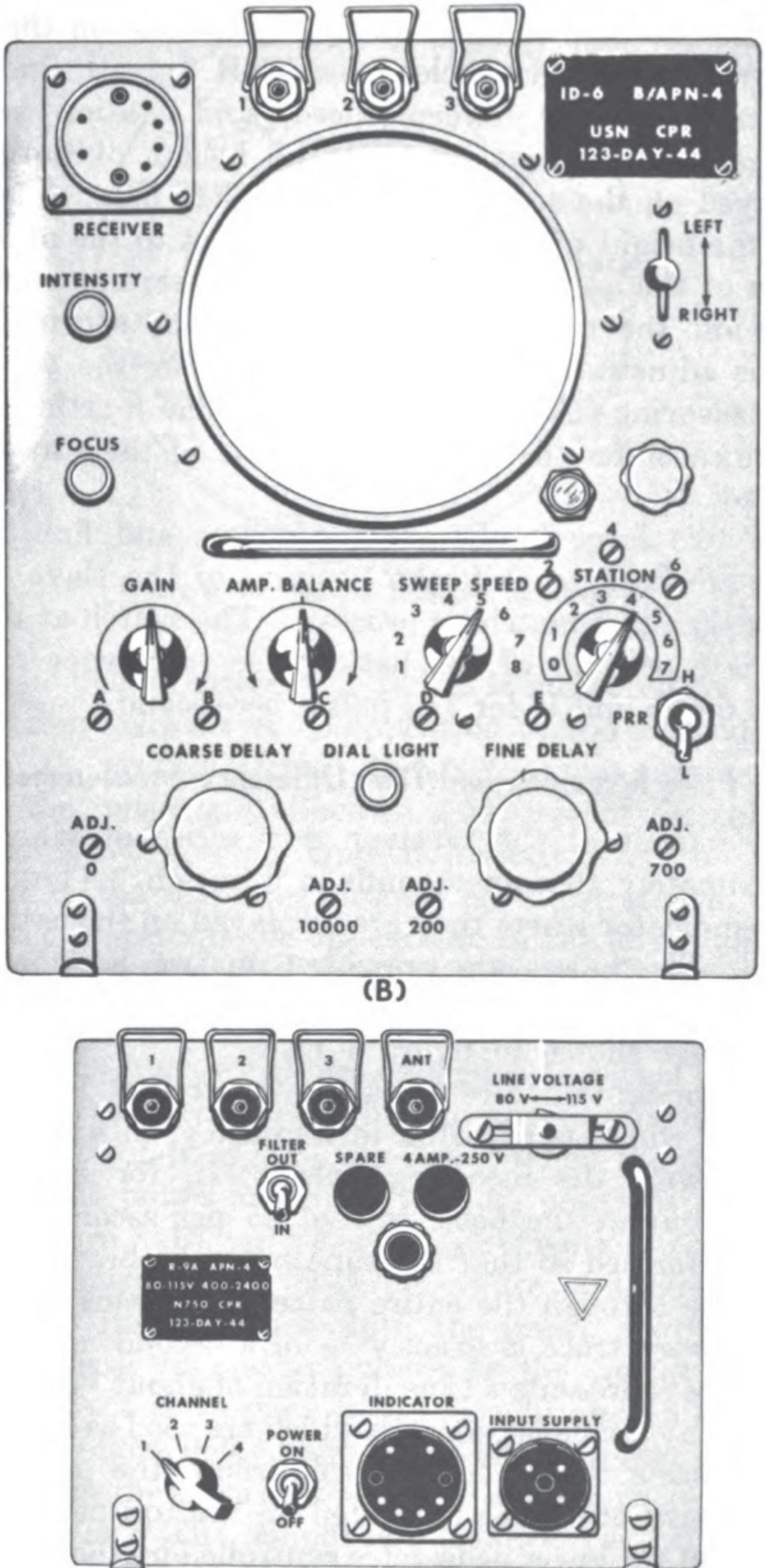


Figure 8-13.—Major units of the AN/APN-4; (A) receiver; (B) indicator.

to make one pair of them remain motionless on the screen.

Four controls just below the C–R tube include gain, amplitude balance, sweep speed, and station selection. The gain adjustment controls the height of both pulses displayed on the screen. The amplitude balance knob adjusts the height of one pulse with respect to the other. By means of the sweep speed knob the appearance of the two pulses on the screen can be changed to accomplish the various adjustments necessary in matching the two signals and measuring their time difference. The fourth knob sets the indicator for the specific pulse rate of the station to be received.

The two large knobs are the coarse and fine controls. These are used to shift the position of the slave pedestal during the pulse matching process. The switch at the lower right is a selector of the basic pulse recurrence rate. (L stands for 25 and H for 33⅓ pulses per second.)

Pulse Matching and Time Difference Measurement

The output of the receiver is a series of video pulses approximately 40 microseconds in duration. These are fed to the indicator where they are displayed on the cathode-ray screen. The pulses are presented on two horizontal lines which are formed in succession with rapid retrace lines in the manner shown in figure 8–14.

The horizontal trace lines are controlled by a crystal oscillator which is adjusted in frequency until it is exactly in step with the incoming pulses. If, for example, the pulses occur at the basic rate of 25 per second, the trace lines are formed so that the time from the beginning of the upper line through the entire pattern and back to the start of the upper trace is exactly $\frac{1}{25}$ of a second. In this case each trace represents a time duration of about $\frac{1}{50}$ of a second. The display includes pedestals which are used as index marks. By adjusting the crystal-control circuit, the pulses can be shifted until one pulse is located on the top pedestal. The position of the lower pedestal is controlled by the delay knobs on the indicator panel, and these are adjusted until the lower pedestal is moved under the lower pulse.

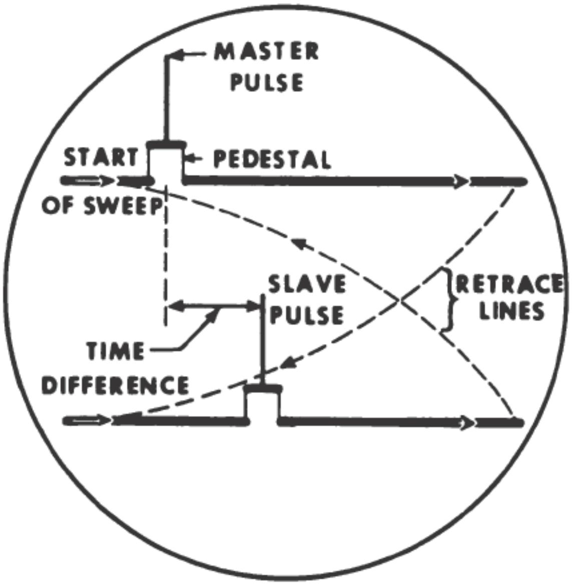


Figure 8–14.—Loran indicator display.

The time delay between the pulses is measured by means of calibration markers which appear on the screen under the control of the crystal circuit. Before the time measurement is made, the pulses are alined in a process of matching in which one wave is superimposed directly over the other. The steps in the matching process are illustrated in figure 8–15, which represents the appearance of the loran indicator screen with different sweep speeds.

The pedestals shown in the first three drawings represent portions of the trace which are expanded to reveal the pulse shapes. The master pedestal on the upper trace is fixed in positions at the left edge of the line. When the set is first turned on, the pulses appear in random positions as shown in (A) of figure 8–15. By slight adjustments of the crystal synchronizing frequency, both pulses are positioned to the left or right on the screen until the image shown in (B) appears. There the master pulse is on the master or upper pedestal and the slave pulse is to the right and on the lower trace. The coarse delay knob is adjusted to bring the lower pedestal under the slave or lower pulse and the pattern shown in (C) results. The amplitude balance control is then adjusted until the pulses are equal in height.

The portions of the traces under the pedestals are then

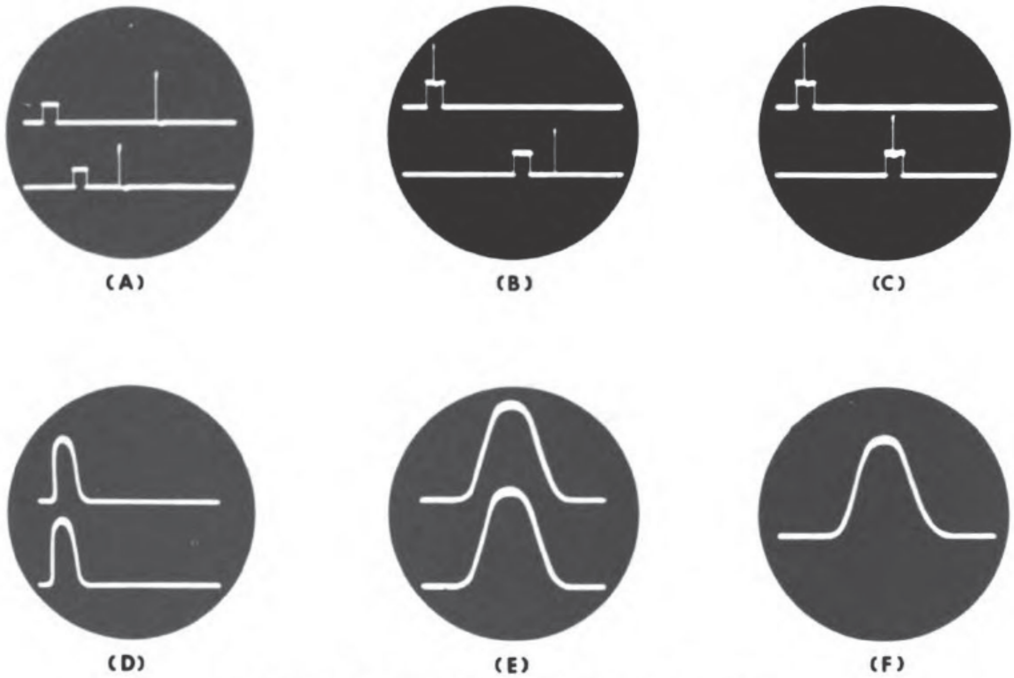


Figure 8–15.—Pulse matching procedure.

expanded by changing the sweep speed to position 2 (750 microsecond sweep) and the result shown in (D) of figure 8–15 appears. The two pulses are placed one above the other by means of the fine delay control and both are then moved to the left end of the trace lines with the left-right toggle switch on the indicator panel. Another adjustment of the sweep speed to position 3 gives the pattern shown in (E). The amplitude balance and gain controls are adjusted until the two pulses are equalized in height.

Another sweep speed adjustment superimposes the two pulses as shown in (F). The amplitude balance and fine delay controls are adjusted again to match precisely the lower left sides of both pulses.

MEASURING THE TIME DIFFERENCE.—The purpose of the preceding steps is to aline the pulses in preparation for measurement of the time interval. This value is determined by means of calibration marks derived from the crystal oscillator circuit and superimposed on the time traces as shown in figure 8–16. The sweep speed adjustment is turned to position 5 causing the removal of the pulses and substitution of the calibration marks. The time interval is read in three steps as illustrated in the figure.

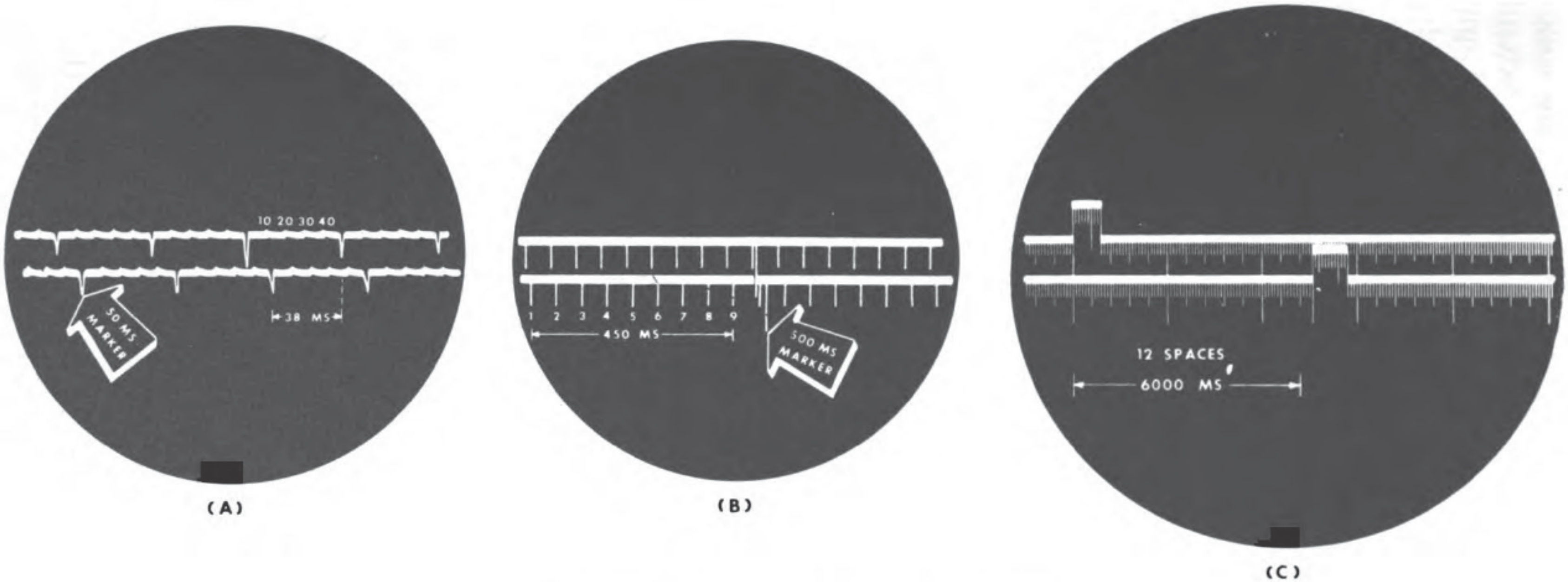


Figure 8-16.—Measuring the time difference.

In (A) of figure 8–16, the fastest of the time-measuring sweeps is shown which produces markers extending above and below each trace. The small upward pips are 10-microsecond intervals and the longer downward pips divide the lines into 50-microsecond intervals. The units and tens of microseconds are measured by using the lower trace as a scale and one of the longer upper markers as a pointer. The interval is read from a long marker on the lower line to the next long marker to the right on the upper line. The interval illustrated in (A) is 38 microseconds. (The fraction of a whole space is estimated.)

The sweep control is then set to position 6 and the display shown in (B) of figure 8–16 results. The longer downward pointing markers divide the trace into 500-microsecond intervals and the shorter markers divide it into 50-microsecond intervals. The time measurement is made as before—the interval is read from the large marker on the lower line to the next large marker to the right on the upper line. If no 500-microsecond marker appears on the lower line, the starting point is the first 50-microsecond marker to the left on the lower line. From this point the number of complete 50-microsecond spaces is counted which are to the left of the first 500-ms. marker on the upper line. The interval illustrated in 450 microseconds plus—the plus being the 38 microseconds previously measured.

In the last step illustrated in (C) of figure 8–16, the sweep is set to position 7, giving the pattern shown. The traces are divided by the markers into intervals of 500 microseconds. The number of complete 500-ms. spaces between the left sides of the upper and the lower pedestals are counted. In the illustration the time value is slightly over 12 spaces, or 6,000 microseconds plus—the plus being the 488 microseconds previously measured.

The three values, 38, 450, and 6,000 microseconds, are then added to give a total time difference of 6,488 microseconds.

A loran receiver of more recent design than the AN/APN–4 is the airborne unit, AN/APN–9. This equipment employs a 3-inch cathode-ray tube and nonlinear sweep; and as a

result, a reduction is made in the number of tubes required in the indicator circuits. The weight of the unit is about 35 pounds and the input power required is approximately 175 watts. The method of matching the pulses in the AN/APN–9 display differs slightly from the procedure used in the AN/APN–4 although the principle involved is the same.

Radar Receiving Set AN/APN–70

Radar Receiving Set AN/APN–70 is an airborne navigational aid used to receive and interpret loran signals. This set is a later development than the AN/APN–4 and the AN/APN–9 equipments and was designed to replace them. The AN/APN–70 is installed in bombers, cargo, transport, and similar aircraft. It contains many features which represent improvements in airborne loran receivers, among which are the following:

1. Direct readings of time delay are obtained on decade-type revolution counters. The time intervals appear in digits denoting microseconds on the revolution counters, the number indicated depending on the elapsed time between the master and slave pulses received.
2. Automatic drift control (ADC) is employed. These circuits allow exact synchronism between the recurrence rate of the transmitting stations and the corresponding rates generated in the receiver.
3. A five-inch cathode-ray tube is used in the indicator unit.
4. Provision is made for navigating along a loran line of position.
5. Many special test points are provided in the set, subassembly construction is used, and adjustment instructions are mounted on the chassis. These features make for greater ease in maintenance and repair.

The major components of the AN/APN–70 are the receiver, the indicator, an antenna coupler, special shock mountings for each of the preceding components, and a viewing visor. The receiver assembly includes an R-F RECEIVER unit, the TIMER unit, the DEFLECTION unit, and the

POWER SUPPLY. Approximately 400 watts of primary power at 115 volts, a. c., in the frequency range from 380 to 1,000 cycles, are required. The receiver assembly weighs 45 pounds and contains 79 tubes.

The r-f receiver unit of the AN/APN–70 set is designed to operate over the standard high-frequency loran band from 1,700 to 2,000 kilocycles, and on the two low-frequency channels from 90 to 110 kc. and from 170 to 190 kc.

The indicator unit displays the loran presentation. It contains the cathode-ray tube, video amplifiers, and the circuits for developing the sweep and blanking voltages. The assembly contains a total of seven tubes; and when combined with the mounting unit, it has a total weight of 18.5 pounds.

The AN/APN–70 receiver uses the same antenna used by other electronic devices (such as communication receivers) in the same airplane. The antenna coupler serves to isolate the loran equipment and to prevent interaction with the other electronic systems which share the common antenna. In addition to isolation of the receiver, the coupler unit also provides a means of matching the unit to the characteristics of different antennas, for amplifying signals to which the set is tuned, and for attenuating unwanted reception. Four stages of amplification are contained in the antenna coupler together with the associated impedance-matching and attenuation circuits.

BASIC PRINCIPLE OF OPERATION.—The receiver gives a direct reading in microseconds of the indicated time difference between the arrival of the master and slave pulses received from the loran transmitting stations in use. Two variable time intervals are generated within the receiver. A reading is obtained by comparing a variable time interval with the elapsed time between reception of the loran pulses, the comparison being made by means of the display on the indicator screen. Each variable time interval is controlled by a crank located on the receiver panel; and when the time interval has been adjusted to coincide with the received interval minus one-half the recurrence interval, the indicated time difference can be read on the associated counter.

Since the receiver contains two delay systems, one reading for a standard loran pair can be retained while the second value from another pair is being taken. This is comparable to using two of the older loran receivers simultaneously. Also, if one delay system fails, the equipment is still usable since the two time-difference readings required for a fix can be obtained from the remaining operating delay system.

The AN/APN–70 equipment provides for reception of low-frequency (LF) loran stations; and in this type of operation, the two time-difference readings corresponding to lines of position appear simultaneously on the revolution counter dials. The simultaneous readings are based on triad operation of the transmitters. The LF loran triad consists of a master station which controls two slaves. The master transmitter is pulsed at twice the recurrence rate of the slaves while the slaves emit pulses at the same recurrence rate. One pulse from each slave is sent during each recurrence period, L, and the master pulses occur at intervals of $L/2$. The master pulses are called X and Z and the slave pulses are known as Y and W. During reception of signals from LF triads, all four pulses appear on the indicator in the sequence X–Y–Z–W. In order that the pips can be identified readily on the screen, the X-pulse is followed closely by a "ghost," resulting in a double vertical deflection.

The two readings given by the revolution counters are plotted on loran charts and enable the operator to determine his location.

The Receiver

The AN/APN–70 receiver assembly is composed of three major units: the R-F RECEIVER, the TIMER, and the DEFLECTION units. These sections are shown in block diagram form in figure 8–17, which also includes the components of the loran indicator.

R-F RECEIVER UNIT.—This portion of the loran receiver is a superheterodyne system, which contains an r-f amplifier, a converter, two i-f amplifiers, a detector, and a video amplifier. Loran signals are received from the antenna coupler by the r-f amplifier, a tuned-grid, tuned-plate circuit. The output of the amplifier is applied to the converter stage.

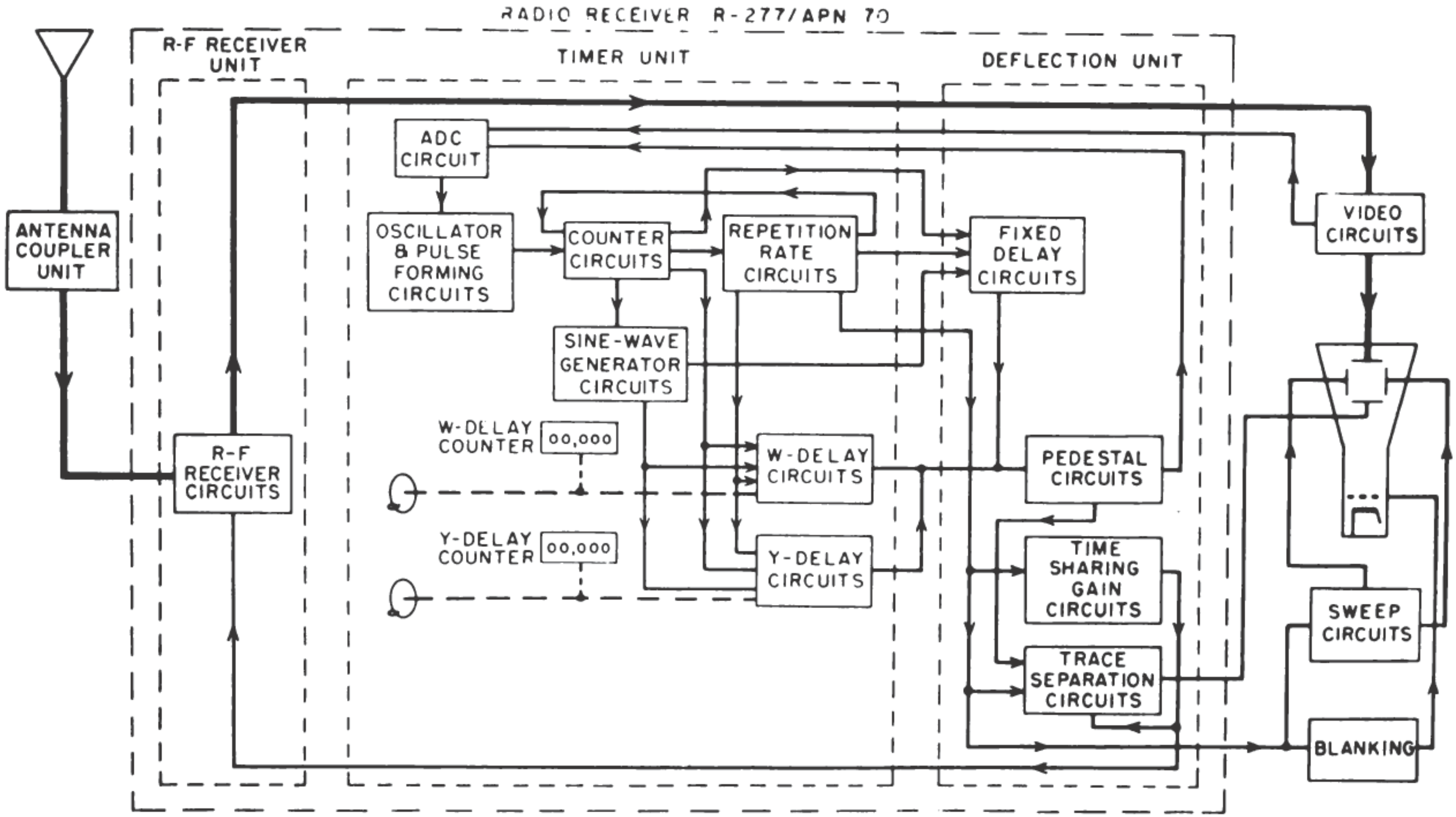


Figure 8-17.—Block diagram of the AN/APN-70 receiver.

One section of the tube is used in a Pierce crystal oscillator circuit that produces mixing voltages. The i-f output of the converter is amplified in the two i-f amplifiers and fed to the detector. The resulting video pulses pass through one stage of amplification and are coupled through a cathode follower in the deflection unit to the video section of the indicator for subsequent application to the vertical deflection system of the cathode-ray tube.

THE TIMER UNIT.—This unit generates a series of pulses serving as the time base of the equipment and produces the variable delay intervals used to measure the time differences of the loran pulses. Also, to insure that the receiving set and the transmitter system are operating at the same recurrence rate, the timer contains circuits for synchronizing the two.

The timing standard in the receiver is an 80-kilocycle crystal oscillator from which is derived (either directly or indirectly) the time bases for the timer, delay, and deflection circuits. The oscillator is synchronized with the time base of the loran transmitter by the action of the AUTOMATIC DRIFT CONTROL (ADC) circuits. The oscillator can be changed in frequency over a narrow range by a reactance tube whose d-c input grid voltage assumes a value corresponding to the degree of synchronism of the receiver circuits with the incoming loran pulses. The grid voltage of the reactance tube is produced by a discriminator tube which compares the repetition rate of the incoming master and slave pulses with the master and delay pulses from the receiver-indicator (which have a pulse rate set by the timer). Any variation in the two rates produces a d-c bias on the control grid of the reactance tube which in turn corrects the oscillator frequency and the resulting pulse rate derived from it.

The sine-wave output of the crystal oscillator is shaped to produce a sharp negative driving pulse which is applied to the COUNTER circuits. The electronic counter contains 12 identical multivibrators and ten identical interstage amplifiers. Each counter stage is a binary (divides the input pulse rate by two). The first 11 of these stages, together with the

ten interstage amplifiers, are used to obtain the repetition rate. The 12th stage is driven by the output of the repetition rate circuits to obtain a square wave which is applied to the TRACE SEPARATION circuits through a 1,625-microsecond delay and the pedestal generator section.

The first multivibrator of the counting series is triggered by 80-kilocycle pulses derived from the PULSE FORMING circuits. The output of the first stage is fed to the grid of the first interstage amplifier tube which drives the second multivibrator. This sequence is repeated throughout the first 11 stages so that the overall division ratio is 2,048 to 1; hence, the counter chain gives one output pulse for every 2,048 pulses fed into it.

The REPETITION RATE circuits accept the output of the counter section and produce the reset pulses which determine the time at which the counter stages reach the count selected by the position of the recurrence rate switch. At that time a pulse is generated to reset the counter chain for the next cycle and to drive the 12th stage. The position of the recurrence rate switch may be set for any one of the 24 loran repetition rates. In addition, the repetition rate circuits supply trigger pulses to the FIXED-DELAY circuits, the TIME-SHARING GAIN circuits, and to the SWEEP circuits in the indicator unit.

The W- and Y-DELAY indicating systems consist of dials, switches, gear trains, gating tubes, wave shapers, goniometers, pulse formers, and thyratrons. These systems are connected to stages three to twelve of the binary counter chain. Each delay system produces one output pulse during each L period, and the occurrence of this output can be varied uniformly and continuously through the range zero to $L/2$ by means of a handcrank. Two dials indicate the microseconds of delay produced at the thyratron of each system. The W and Y systems are identical in construction and operation except that their outputs appear in successive $L/2$ periods for operation with LF loran signals (dual presentation). With high-frequency (single presentation) loran reception, only one delay system operates, as determined by the setting of the W–Y switch.

THE DEFLECTION UNIT.—In addition to the low-voltage power supply, the deflection chassis contains circuits that receive signals from the timer unit. These signals are used to synchronize and trigger waveforms that perform the following functions:

1. Generate three independent bias voltages for the three TIME-SHARING GAIN circuits.
2. Generate waveforms to drive the sweep generator in each position of the FUNCTION switch.
3. Generate trace-separation waveforms when required by the function selected at the control panel.

In single presentation, the TIME-SHARING GAIN CONTROLS enable the operator to adjust the receiver gain to an independent level on each trace appearing on the indicator screen. Either the W- or the Y-delay system may be independently selected by a control switch. Thus the delay reading and the gain setting of one pair of loran stations may remain on one counter dial and gain control knob while the operator is matching a second pair of loran pulses using the second delay system. The output of the time-sharing gain circuits also supplies bias to the r-f and i-f stages of the r-f receiver unit.

The TRACE-SEPARATION circuits are connected to the lower vertical deflection plate of the cathode-ray tube to apply the pedestals from the PEDESTAL GENERATOR. The FIXED-DELAY stage provides a 1,625-microsecond delay for the trigger governing the appearance of the master pedestal. For dual presentation, one trigger signal for every $L/2$ interval is provided; while in single presentation, only one trigger signal for every alternate $L/2$ is required.

The PEDESTAL CIRCUITS receive pulses from the fixed-delay and variable-delay circuits and generate waveforms to produce the master and slave pedestals. The output waveforms are supplied by a cathode-coupled, one-shot multivibrator which provides a square wave of approximately 500 microseconds for the fast sweeps, and 1,200 microseconds for the slow and medium sweeps. In position 1 of the FUNCTION switch, the multivibrator generates the pedestals seen on the traces on the indicator tube. In other positions

of the switch, the pedestals are used to generate the traces, and only the video signals present during the portion of the pedestal covered by the trace are shown on the indicator tube.

The Loran Indicator

As shown in figure 8–17, the loran indicator contains the sweep circuits for developing the horizontal deflection voltages applied to the cathode-ray tube blanking circuits, the video circuits, and the cathode-ray tube. In addition, the assembly contains two high-voltage rectifiers which supply d-c potentials for the C–R tube.

The sweep and blanking circuits are triggered by the reset pulses from the repetition rate circuits. A 6AU6 tube is used as a horizontal sweep generator which supplies a sawtooth wave that is applied to the left horizontal deflection plate of the C–R tube. A portion of the output is also fed to a phase inverter stage to give an output wave 180 degrees out of phase with the sweep generator output and which is applied to the right deflection plate, thus providing two voltages for push-pull horizontal deflection.

The blanking circuit extinguishes the electron beam in the indicator tube during retrace intervals in which the grid in the indicator tube is driven highly negative with respect to the cathode. A d-c restorer diode clamps positive swings of the C–R grid to the voltage set by the BRILLIANCE control and establishes the level about which blanking takes place. An R–C combination in the blanking circuit insures that the traces seen on the screen of the indicator tube are delayed until after the start of the sweep to remove irregularities in the initial parts of the sweep cycle.

Video signals derived from the r-f receiver unit are amplified in the video circuits and are applied to the upper vertical deflection plate of the cathode-ray tube. A 300-kilocycle trap in the cathode circuit of the last video amplifier is provided as a low-frequency, i-f filter.

The d-c voltages needed for operation of the cathode-ray tube are supplied by low-voltage, regulated power supplies in the receiver unit and by the two high-voltage rectifiers in the indicator assembly. One high-voltage rectifier pro-

duces a d-c potential of 1,300 volts, positive with respect to ground which is applied to the indicator tube through a cap connection. The other high-voltage supply develops 1,300 volts, negative with respect to ground and is applied to the cathode of the tube through a potentiometer used as the Focus control. The indicator tube is a type JAN 5CP1–A.

QUIZ

1. Which of the following is correct concerning low-frequency radio range stations?
   a. The center tower of an Adcock system is bidirectional.
   b. The Adcock antenna system is comprised of four towers.
   c. Diagonally opposite towers are operated simultaneously.
   d. Marker beacons are not associated with range stations.
2. The center tower of the Adcock system is fed by a transmitter which delivers a
   a. series of dot-dash characters
   b. series of dash-dot characters
   c. 1,020-cycle output
   d. carrier frequency which is 1,020 cycles lower than the radiation of the other four antennas
3. In operation of the low-frequency range, a cone of silence exists over the
   a. fan marker
   b. Z marker
   c. "A" quadrant
   d. "N" quadrant
4. Which of the following is correct?
   a. Fan markers are located in the "A" or "N" quadrants.
   b. Fan markers emit a 7,500-cycle tone.
   c. The bone-shaped fan marker radiation pattern gives sharper identification.
   d. The fan marker signals are received on a range receiver.
5. Which of the following is correct?
   a. The four courses of VAR are three aural and one visual.
   b. The visual course is flown by observing the position of the towers.
   c. The center antenna radiates the carrier for both the aural and visual signals.
   d. The aural signals are received as a combination of the 90-cycle and 150-cycle tone.

6. Which of the following statements is true concerning the ILS glide path?
   a. The receiver employs an Armstrong oscillator.
   b. The system gives vertical guidance to the pilot.
   c. The system gives horizontal guidance to the pilot.
   d. The system directs the pilot to the end of the runway.
7. The ILS employs marker beacons which
   a. are identified by tone modulation only
   b. are located approximately 20 miles from the end of the runway
   c. indicate the position of the plane along the approach to the runway
   d. operate between 200 and 400 kc.
8. The VOR
   a. provides only 4 courses
   b. navigational information is presented in an aural form
   c. operates in the UHF range
   d. provides a pilot with courses from any point in its service area
9. The reference phase of the VOR station is
   a. broadcast in a figure-of-eight pattern
   b. broadcast in a nondirectional pattern
   c. broadcast in only four directions
   d. not independent of azimuth
10. Which is the correct statement?
    a. DME units operate similiarly to IFF and radar beacons.
    b. The combined omni and DME information provide only a part of the primary navigation data.
    c. The ground unit of the DME gear is called an interrogator.
    d. Any VHF pulse will trigger DME gear.
11. The AN/ARN–14 radio receivers
    a. provide airmen with all radio aids to navigation now available in the VHF range
    b. cover a frequency range of 100 megacycles
    c. will not receive voice transmissions
    d. do not differentiate between true and reciprocal courses
12. The vertical flag alarm of the course indicator ARN–14 indicates OFF when the
    a. received signal strength is too strong for use
    b. received signal is too noisy for use
    c. signal is overmodulated
    d. received signal strength is too weak for use
13. The 0-degree marker on the rotating card of the course indicator ID–250/ARN always represents
    a. relative bearing
    b. magnetic north
    c. the heading of the aircraft
    d. true north

14. The AN/ARN–14E (Collins) receiver employs
    a. double conversion TRF
    b. double conversion superheterodyne ECO controlled
    c. double conversion superheterodyne with crystal control
    d. single conversion superheterodyne with crystal control

15. The principal receiver of the ARN–14 can be considered as being divided into which of the following three major sections?
    a. Radio frequency, VHF, and instrumentation
    b. Radio frequency, audio frequency, and instrumentation
    c. VHF, audio frequency, and instrumentation
    d. Radio frequency, audio frequency, and CW

16. What is the minimum number of loran stations required for a loran fix?
    a. Two pairs
    b. Four pairs
    c. Eight pairs
    d. Two stations

17. Which of the following is correct concerning loran equipment?
    a. The slave transmitter pulses at a fixed rate, independent of the master.
    b. The slave transmitter is triggered by the master station.
    c. A line of position cannot be determined by one pair of stations.
    d. Standard transmitters operate on five channels.

18. The crystal frequency control knob of the APN–4 indicator
    a. brings the sweep in the C–R tube into exact synchronism with the incoming pulses
    b. introduces small changes in the frequency of a crystal oscillator
    c. controls focus and intensity
    d. moves the pulses to left or right on indicator

19. To make the time measurement on an APN–4 screen
    a. the pulses should not overlap
    b. the pulses should be shifted until they are located 25 microseconds apart
    c. the pulses are first alined so that one wave is superimposed directly over the other
    d. only one pulse is visible

20. Which of the following is correct concerning AN/APN–70 equipment?
    a. A three-inch CRT is used in the indicator unit.
    b. The receiver assembly includes only an r-f receiver and power assembly.
    c. The receiver uses the same antenna used by other electronic devices in the same airplane.
    d. No antenna coupler is necessary.

21. A loran fix, using APN–70, can be obtained by how many pairs of stations?
    a. Four
    b. Eight
    c. One
    d. Two

22. The APN–70 equipment employs a
    a. TRF system
    b. single delay system
    c. receiver that covers only the high-frequency loran band
    d. receiver that will receive low-frequency loran stations

23. The timer unit of APN–70
    a. insures that the receiving set and transmitter system are operating at the same recurrence rate
    b. employs a 90-kc. crystal oscillator to provide a timing standard
    c. employs an oscillator that is synchronized with the time base of the loran transmitter by the action of the fixed delay circuits
    d. generates one pulse serving as the time base of the equipment

24. The deflection unit of the APN–70
    a. generates one bias voltage for the three time-sharing gain circuits
    b. generates waveforms to drive the sweep generator in each position of the function switch
    c. does not receive signals from the timer unit
    d. does not contain a low voltage power supply

25. The horizontal deflection voltage for the APN–70 CRT is developed in the
    a. deflection unit
    b. timer unit
    c. indicator
    d. receiver

CHAPTER 9

INTRODUCTION TO RADAR BOMBING ATTACHMENTS

In the days before the development of radar, bombing attacks could be made only during the day, and then, only when the weather was clear. The use of radar changed this completely. Radar provides a means for detecting the enemy, for directing the pilot in for an attack, and for automatically releasing the bombs at the correct position, even though the target is obscured by darkness or overcast. Search radar alone can be used by a skillful operator to direct a bombing approach and to make the release; however, it is the use of specialized units called RADAR BOMBING ATTACHMENTS which makes radar bombing a precision operation.

Radar bombing attachments function as bombsights and compare favorably with the best of optical bombsights in accuracy. They are installed in most medium and heavy bombers and are used in making both high and low level attacks. In many installations, provision is made for the automatic firing of rockets in addition to the release of bombs.

The following pages are an introduction to this type of electronic equipment. The discussion is concerned principally with the bombing problems which are solved by radar attachments and the general methods by which the solutions are made.

FALL OF BOMBS IN VACUUM

In order to release a bomb from an aircraft so that it will strike a target, it is necessary to direct the aircraft along the proper course and to release the bomb at the proper point in space. As a first approach to the problem of finding the location of the release point, consider an imaginary bombing situation—the fall of a bomb in a vacuum after release from an aircraft. Assume that the aircraft releasing the bomb is flying at a constant altitude and with constant speed along a straight-line course which passes directly over a stationary target. After release, the bomb is affected by only two forces—gravity and the force resulting from the forward motion imparted to it by the aircraft. At the instant of release, it is traveling horizontally at the same speed as the plane and in the same direction. But gravity begins to pull it down immediately. The combination of the two forces causes the bomb to follow a curved path called the VACUUM TRAJECTORY, which is illustrated by the curved dotted line in figure 9–1.

In the vacuum condition, the forward velocity of the bomb in flight remains equal to that of the aircraft since there is no air resistance to slow it after release. Upon impact, the plane is directly above the target; and through the trajectory, the bomb is directly under the plane.

In figure 9–1, the release position is above a point on the ground which is located from the target at a distance labelled R. This horizontal distance is called the GROUND RELEASE RANGE for vacuum. It forms the base of a right triangle called the RELEASE TRIANGLE, the altitude of which is the absolute altitude of the plane. The hypotenuse, S of the triangle is called the SLANT RELEASE RANGE.

The release triangle forms the basis for calculating the location of the release point. One of the important factors in the calculation is the time required for the bomb to fall.

In vacuum, the time of fall depends only upon the altitude from which the bomb is dropped and is independent of the forward speed imparted by the aircraft. Two bombs dropped at the same time in a vacuum from the same altitude, one

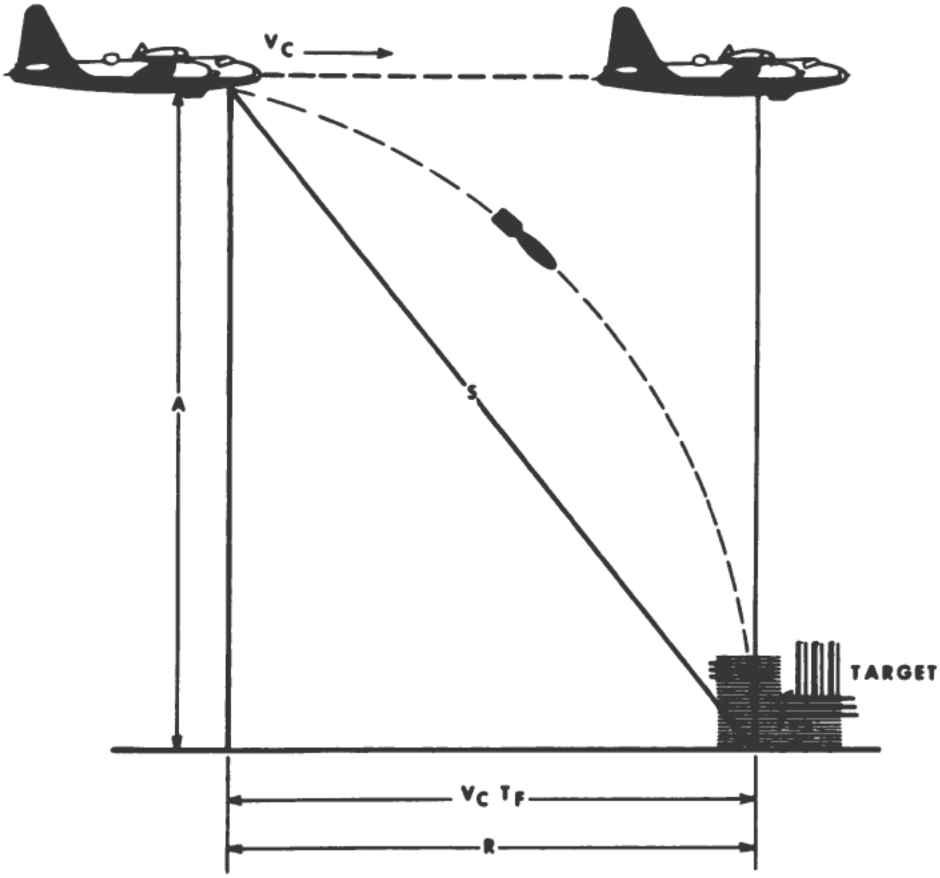


Figure 9–1.—Fall of bomb in vacuum.

from a speeding plane and one from a balloon, would hit the earth at the same instant. They would, however, land at a considerable distance apart, since the bomb from the balloon would drop straight downward, and the one from the moving airplane would have a curved trajectory. In either case, the time of fall could be easily found, since, in vacuum, a falling body travels 16 feet the first second and accelerates about 32 feet per second during each succeeding second. The formula, relating the distance through which the object falls to time, is as follows:

$$D=\frac{1}{2}gt^2,$$

where D is the distance, g is the acceleration of gravity (approximately 32 feet per second), and t is the time in seconds.

As an example, suppose it is known that the altitude of

the plane in figure 9–1 is 1,600 feet, and it is required to find the time of the fall of the bomb released from it. Applying the formula given above:

$$D = \tfrac{1}{2}gt^2$$
$$1{,}600 = 16t^2$$
$$100 = t^2$$
$$t = 10 \text{ seconds.}$$

During the time it is falling, the bomb travels horizontally toward the target at the same forward speed it had at the instant of release, since, in the condition assumed, there is no air resistance to retard it. The speed at which it approaches the target is then identical with the closing speed of the aircraft, that is, the rate at which the plane moves toward the target or closes upon it. Hence, the horizontal distance covered by the bomb is equal to the product of the closing speed (or velocity) of the plane and the time of fall of the bomb. This distance is the ground release range of the release triangle, the horizontal distance between the release point and the target measured at the target level. In equation form it is expressed as follows:

$$R = V_c t_f,$$

where R is the ground release range for vacuum, V_c is the closing speed of the aircraft, and t_f is the time of fall of the bomb.

Closing speed, V_c, is used in the formula instead of groundspeed, since the former term includes the case of moving targets. In actual conditions when air resistance is present, the closing speed depends upon the airspeed of the plane, the wind velocity, and the motion of the target.

If a plane could fly in a vacuum, it would be easy to predict the horizontal ground range at which to release the bomb so as to score a hit on the target. The only information needed would be the altitude and the closing speed. For example, assume that the closing speed of the aircraft is 200 knots and that the altitude is 1,600 feet so that the bomb requires 10 seconds to fall. Since a speed of one knot is equal to

1.69 feet per second, the bomb travels 200×1.69 or 338 feet per second in the horizontal direction. The horizontal distance it covers from the time of release to the time of impact is 338 feet per second times 10 seconds or 3,380 feet. Therefore, the bomb should be released when the plane is directly above a point on the ground which is 3,380 feet from the target.

In general, to hit a target when flying in a vacuum (if this were possible), it would be necessary to fly on a course which passes over the target and to release the bomb at a ground release range equal to $V_c t_f$ feet, where V_c is the closing speed in feet per second and t_f is the time of fall in seconds. But to be of any use, this information must be put in a different form—a form which lends itself to radar methods of distance measurement.

Looking back at figure 9–1, it is seen that the actual distance separating the release point and the target is the slant distance, S, or the hypotenuse of the release triangle. The two legs of this triangle are A, the altitude, and $V_c t_f$, the ground release range. The slant release range can then be found in terms of these quantities by application of the rule of right triangles: The hypotenuse of a right-angled triangle is equal to the square root of the sum of the squares of the two legs. Accordingly,

$$S=\sqrt{A^2+(V_c t_f)^2},$$

where S is the vacuum slant release range, A is the absolute altitude of the plane, and $V_c t_f$ is the ground release range for vacuum.

This equation locates the release point in a form which is well adapted to radar bombing, since radar measures the slant range to ground targets with great accuracy. However, the equation is only an approximation, since it was derived on the assumption that the bomb was dropped in vacuum. It is now necessary to consider the effects of air resistance on falling bombs and to change the slant release range formula accordingly.

FALL OF BOMBS IN AIR

When a bomb is dropped from an airplane under actual conditions, two factors not present in vacuum affect its motion. These are AIR RESISTANCE and WIND.

Air resistance has the following important effects on the falling bomb:

1. The vertical velocity is reduced, thereby increasing the time of fall.
2. The horizontal velocity is reduced, causing the bomb to lag behind the aircraft after release.

The amount of reduction made in either velocity varies with the airspeed of the plane, the altitude, and the physical properties of the bomb, such as size, weight, and shape.

When released in air, the horizontal distance passed over by the bomb during its flight differs considerably from that of the bomb in vacuum because of the increase in the time of fall and the decreased forward speed. As a result, the bomb strikes the earth at some distance astern of the aircraft as shown in figure 9–2.

In this illustration, the bomb dropped in air follows the curve labelled AIR TRAJECTORY and strikes the target at point B. During the time of its fall it travels the horizontal distance, AB, the ground release range for air. During this same interval of time a bomb released in vacuum would travel a horizontal distance represented in the figure as AC, the sum of the ground release range for air and the additional distance BC, called the TRAIL. Trail is the horizontal distance astern of the aircraft at which the bomb strikes the earth when released in air. It can also be defined as the horizontal interval separating the vacuum trajectory and the air trajectory after t_f seconds, the time of fall in air. Hence, trail is the amount by which the vacuum range exceeds the ground release range for air.

The trail distance varies with the air resistance which, in turn, is dependent on the speed of the air past the bomb. Hence, the trail value is governed by the airspeed of the bomb, or the plane, at the time of release. In addition, trail varies with the altitude and with the physical characteristics

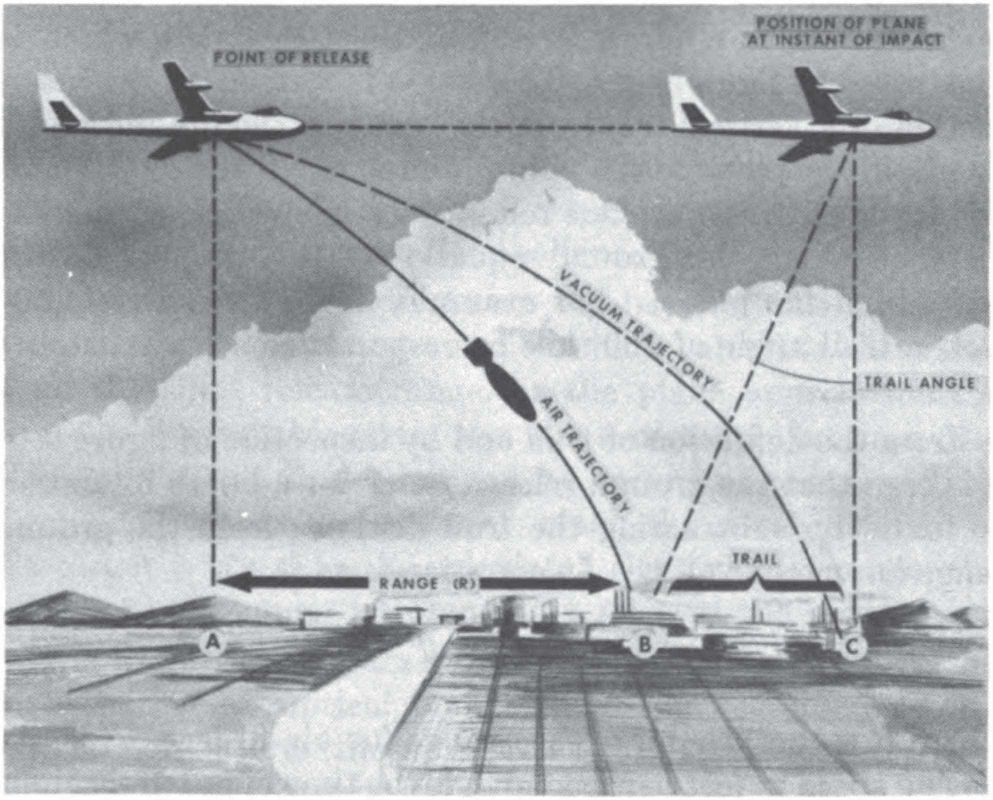


Figure 9–2.—Trajectories in air and in vacuum.

of the bomb. It is important to note that these three factors which determine the trail—airspeed, altitude, and bomb characteristics—are unaffected by the presence of wind. Therefore, trail is independent of wind and has the same value in a headwind or a tailwind that it has in still air. The principal effect of winds along the line of the heading of the plane, that is, either headwinds or tailwinds, is the change made in the closing speed of the aircraft. Assuming that the target is stationary, if there is no wind, the closing speed is equal to the true airspeed of the plane. In a headwind, the closing speed, V_c, equals true airspeed minus wind velocity. In a tailwind, V_c, equals true airspeed plus wind velocity. The trail value remains unaffected and is the same for all three cases.

Trail and time-of-fall values for each type of bomb are determined by Proving Ground tests and are printed in ballistic tables. In the tables time of fall is always given in seconds. Trail, however, may be expressed in one of two

ways: in feet or in angular units. In the latter form, the measurement is made in terms of the trail angle which is illustrated in figure 9–2. This angle is formed at the intersection of a vertical line from the plane to the ground and a line from the plane to the point of impact. The angular unit employed is the MIL. One mil is the angle which subtends a distance along the ground equal to 1/1000th part of the altitude of the plane. For example, if the altitude is 1,500 feet, a trail angle of 100 mils corresponds to a trail distance of 150 feet.

From the definition of trail and by inspection of figure 9–2, it is seen that the ground release range for a bomb in air can be found by subtracting the trail distance from the ground range for vacuum, $V_c t_f$. In equation form this is

$$R = V_c t_f - T,$$

where R is the ground release range for air in feet, V_c is the closing speed in feet per second, t_f is the time of fall in seconds, and T is the trail in feet.

One more quantity must be added to make the ground range equation more general. When, instead of a single bomb, a train of bombs is to be dropped on a target, it is desirable to cause the first bomb to "lead" the target, or to fall short of it. Let the desired lead distance be represented by L, a number of feet. Then the ground release range for the first bomb of the train becomes

$$R = V_c t_f - T + L.$$

The lead distance, L, is a correction for the trail value, causing the ground release range to exceed the value required to hit the target by the amount equal to the lead distance desired. In the case of a single bomb, L is taken as zero in the equation above.

The slant release range for air bombing, the hypotenuse of the release triangle, can now be found by substituting the ground release range given above for the corresponding value in vacuum. Since the altitude, A, is the same in both the

vacuum and the air release triangles, then the slant release range for air is

$$S=\sqrt{A^2+(V_c t_f-T+L)^2},$$

in which S is the slant range, A is the absolute altitude of the plane, V_c is the closing speed, t_f is the time of fall of the bomb, T is the trail, and L is the lead.

Radar bombsights operate on the basis of this equation. They contain computing circuits which calculate the value of S, the slant release range, as the plane approaches the target. During this time, the slant distance between the plane and target is determined by means of radar. When the plane reaches the point at which the slant distance to the target is equal to the calculated slant release range, the bombing attachment automatically releases the bombs.

It is useful to compare this general principle of operation with that of an optical bombsight. The computer of the optical sight solves the same release triangle employed by the radar device, but it derives the value of the angle at the apex of the triangle instead of slant release range. This angle, called the DROPPING ANGLE, is illustrated in figure 9–3.

During the bombing approach with the optical bombsight, a telescope, which is the part of the optical system which corresponds to the radar screen, is kept trained on the target.

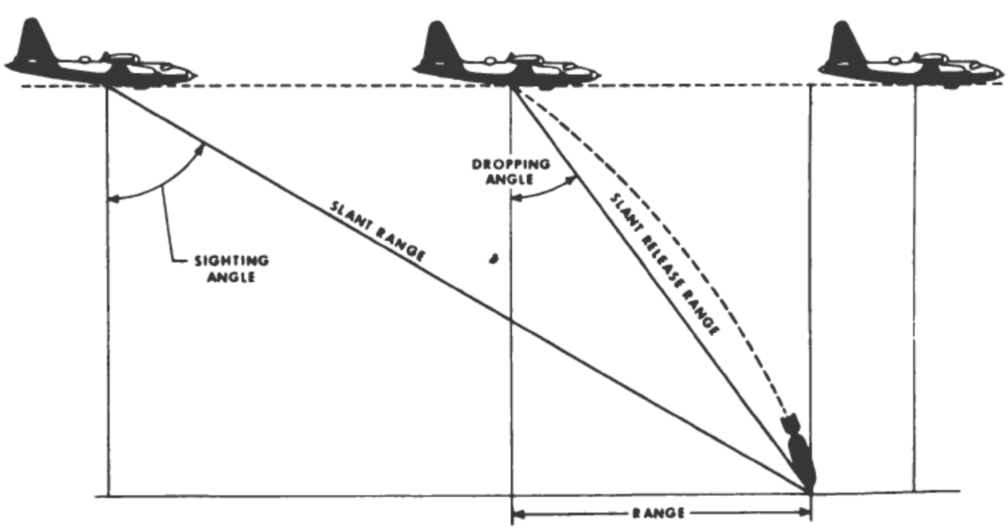


Figure 9–3.—Slant range and dropping angle.

The line of direction which the telescope makes with the vertical is called the sighting angle. When the sighting angle becomes equal to the computed value, the dropping angle, the release point has been reached.

EFFECTS OF CROSS WIND.—Cross wind affects both the flight of the plane during the bombing run and the trajectory of the bomb after release. To achieve a general solution for the problem of cross wind bombing, compensation must be made for both these effects. This solution is illustrated in figure 9–4. In the figure, three quantities appear which are not present when bombing is conducted in still air. These are the DRIFT ANGLE, the distance called CROSS TRAIL, and the distance called RANGE COMPONENT OF CROSS TRAIL.

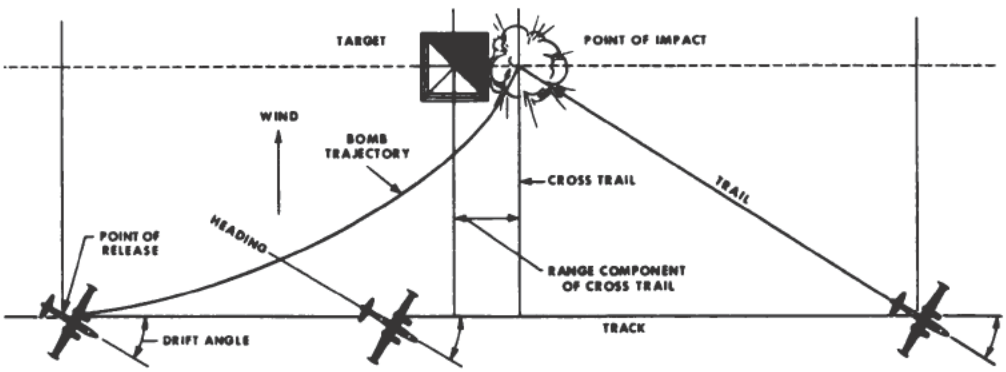


Figure 9–4.—Bomb released in a cross wind.

The drift angle pertains to the heading of the aircraft with respect to the track made good. Assume that the wind is horizontal only and that it is constant in velocity and direction. The wind may be thought of as a large block of air in which the plane is moving. The motion of the block of air tends to carry the plane sideways as it progresses through it. Under these conditions, if the plane is to fly along the track illustrated in figure 9–4, it must head into the wind. The angle between the plane's heading and the resulting track is called the DRIFT ANGLE.

To allow for the tendency of the wind to carry the bomb sideways and to blow it beyond the target, the aircraft flies a track to windward of the target, as shown in figure 9–4. The perpendicular distance from the track to the point of

impact is the cross trail distance. The value of the cross trail depends on the amount of trail and the value of the drift angle, being equal to the product of the trail distance and the sine of the drift angle.

In the diagram the bomb misses the target, the point of impact being located a short distance beyond it. This error is called the RANGE COMPONENT OF CROSS TRAIL. This component occurs because of the angle which the trail line makes with the track. The trail distance depends only on airspeed, altitude, and the physical characteristics of the bomb, and is independent of wind and drift angle. Trail is always measured along the line of the heading of the plane, and its value is the distance astern of the plane at which the bomb hits the ground. This distance is not equal to the interval separating the plane and the target when the trail is measured at an angle to the track, as in the cross wind condition shown in figure 9–4. As a result, the point of impact does not coincide exactly with the target as it would if the drift angle were zero and the plane passed over the target. The error involved is usually very small. For example, with an airspeed of 130 knots, an altitude of 4,000 feet, and a drift angle of 15 degrees, the range component of cross trail is only about seven feet.

Neither radar nor optical bombsights make any correction for the range component of cross trail because of the negligible amount of the error. Optical bombsights provide a means for making a cross trail correction while radar bombsights do not. Because of this, radar sights are a little less accurate than optical sights at high altitudes; however, in low altitude bombing the cross trail error is very small, and, like the range component, can be ignored without greatly affecting the result. The only provision made in typical radar bombing attachments for solving the cross wind problem is a means of setting the drift angle to prevent the plane from being blown off the desired course. During the approach in radar bombing, the plane follows a type of "collision" course which passes over the target. This course is set by finding the correct drift angle and by holding the

aircraft steady on the correct heading. The method by which the drift angle is selected is described in a later section.

Effects of target motion.—Target motion, insofar as it affects the solution of the bombing problem, is considered as an apparent wind. If the target is in motion in the same direction as the plane and along the line of its heading, the effect is similar to that of a headwind which reduces the closing speed. Motion of the target toward the plane along this line produces the same result as a tailwind which increases the closing speed. In either case, the principal factor which is changed in the bombing calculation is the closing speed; the remaining factors—trail, time of fall, and altitude—remain the same as for still air.

Straight-line motion of the target across the heading of the plane causes an apparent drift, and hence gives the same effect as a cross wind. The radar bombsight is equipped to measure the closing speed with accuracy and to compensate for wind drift, thereby taking into account the effects of wind. Since target motion produces exactly similar effects it adds no new problem.

RADAR SOLUTIONS OF BOMBING PROBLEMS

The Release Point Calculation

The preceding discussion of bombing from aircraft in level flight reveals that two basic problems are involved in this type of operation. These are the release point calculation and the problem of setting a collision, or intercept, course during the approach to the target. Radar bombing attachments operating in conjunction with search radar are capable of solving at least one, and in many cases, both of these problems. In the installations which make both solutions, a separate cathode-ray indicator is included for observing the target and presenting the bombing data. The screen presentation in these attachments is stabilized by means of a gyroscopic stabilizer unit.

Some of the bombing attachments are designed to solve the release point problem only. In these, no separate bombing indicator is included, and the data used in the

bombing operation are displayed on the screen of the associated search radar.

In a typical installation of the type of equipment which solves both bombing problems, the major components are as follows:

1. The INDICATOR ASSEMBLY, the screen of which displays the same information which appears on the associated search radar screen and, in addition, a reference range marker called a TRACKING LINE.
2. A CONTROL UNIT which contains a computer used for solving bombing-triangle problems and the control circuits with associated dials for applying information to the computer.
3. A SYNCHRONIZER which supplies range and azimuth sweep voltages for use in the indicator assembly, the pulse which develops the tracking line, and the pulse which determines the time at which the bombs are released.
4. A RECTIFIER which supplies the d-c voltages used in the other major units.
5. A GYRO STABILIZER and BOMBSIGHT MOUNT containing the controls with which the operator directs the course of the plane during the bombing approach.

The general method employed in radar bombing attachments consisting of the above units is briefly described as follows: The computer circuits in the control unit derive two voltages. One, called the slant release voltage, is proportional to the slant distance separating the plane and the target when the bombs should be dropped (the slant release range). The other, called the slant tracking voltage, is proportional to the slant distance to the target at any moment during the bombing run. The tracking voltage continually decreases as the plane closes on the target. Both derived voltages are applied to the synchronizer where each determines the time at which a corresponding pulse is produced. When the two voltages are equal, the two pulses occur together, signifying that the slant distance from the plane to the target is equal to the computed release

range. When the pulses are combined, a trigger pulse is formed which is applied to the release circuit with the result that the bombs are dropped.

Thus, the complete release problem is based on two lesser ones—that of producing a voltage proportional to the slant release range and one proportional to the slant tracking range. The procedure used in the solutions to both problems is based on solving bombing triangles for the hypotenuse (slant range) when the two sides (altitude and ground range) are known.

A typical computing method of solving the triangles is as follows: The output voltages of a two-phase, a-c generator are adjusted in amplitude so that one voltage is proportional to the altitude of the triangle and the other to the ground range. Since the voltages differ in phase by 90 degrees, the vector sum of the two is proportional to the slant range to be found. The summation is made by applying both components to the input of a mixer-amplifier tube, the output of which is rectified in the synchronizer and used as a control voltage to determine the location of a range pip on the screen.

Slant release range solution.—The derivation of the slant release voltage by the computer is based on the equation developed in the discussion of the release point in air. This equation is

$$S=\sqrt{A^2+(V_ct_f-T+L)^2},$$

in which S is the slant release range, A is the altitude, V_c is the closing speed, t_f is the time of fall of the bomb, T is the trail, and L is the lead.

To solve the equation for S, the 90-degree output voltages of the computer generator are adjusted so that one is proportional to A, the absolute altitude of the aircraft, and the other to (V_ct_f-T+L), the ground release range for bombs dropped in air. The application of these two components to the grid of the release mixer-amplifier stage then produces an output which is proportional to the vector sum of the two, or the slant release range to be found.

The adjustments of the two generator voltages, the ground range and altitude phases, are made by manually setting

the appropriate values on five dials mounted on the control unit with each dial representing a term in the right-hand side of the range equation. The adjustment in each case determines the setting of a potentiometer which makes a change in one or the other of the generator voltages; the change made being proportional to the reading of the corresponding dial.

The information required for setting the altitude value is usually provided by the altimeter of the aircraft. The trail and time-of-fall values are taken from bombing tables which give the correct dial readings for both terms for each value of airspeed and absolute altitude. The lead adjustment is made to fix the distance at which the first bomb of a train is to fall short of the target.

The final adjustments of the control-unit dials and the corresponding potentiometers except that of closing speed are made just before the bombing run begins. The closing-speed adjustment must be made and constantly corrected as the plane approaches the target so that the effects of wind and target motion can be taken into account in the calculation. The information required for making this adjustment is provided by the radar screen on which the operator observes the changing range of the target as the plane closes in on it. The operation of setting the closing-speed potentiometer is called TRACKING. The purpose of the operation is to produce a voltage in the computing circuits which is exactly proportional to the relative speed of the plane with respect to the target. The appearance of the bombing screen during the tracking adjustments is shown in figure 9–5.

The radar presentation shown in figure 9–5 is a type-B display—target azimuth is indicated by the horizontal position of the echo trace; target range is represented by the vertical distance of the target trace from the lower side of the screen.

Two traces appear in the illustration. One is the radar echo of the target to be bombed and is provided by the operation of the search radar. The other trace is produced by a pulse supplied by the synchronizer of the bombing attachment and is called the TRACKING LINE. This line is a variable range

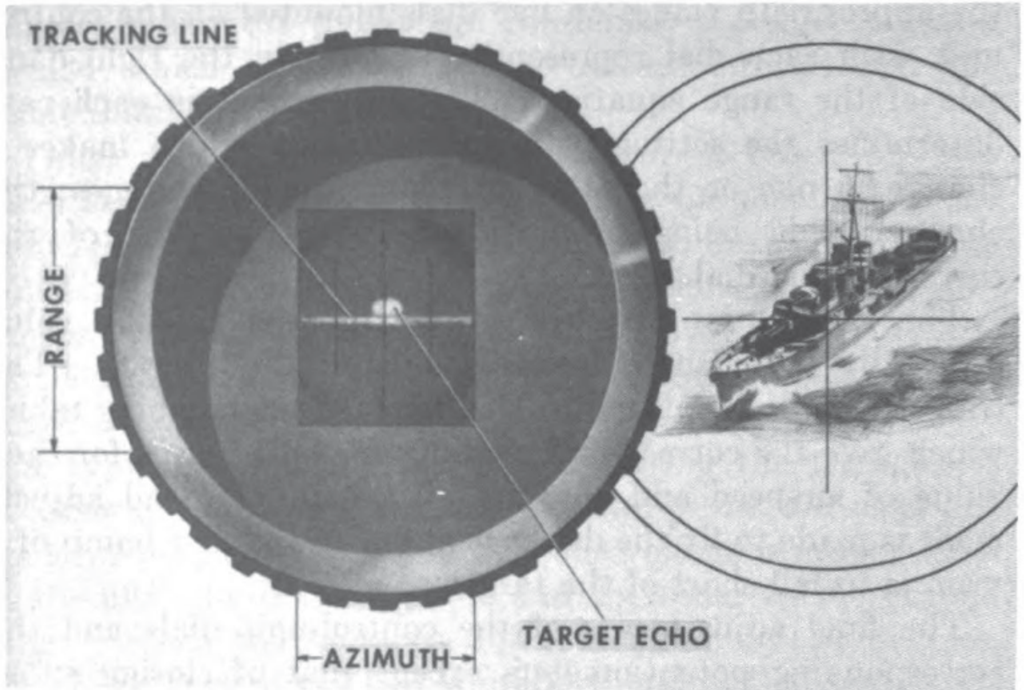


Figure 9–5.—View of indicator.

marker. Its vertical position (or range) at any moment depends on the voltage derived by solving the tracking triangle.

When the target is first sighted during the search phase of the bombing operation, the operator adjusts the position of the tracking line on the screen by means of a LOCATOR control so that the line rests just below the target. As the plane closes the range, the target image drifts downward on the screen. When it first touches the tracking line, appearing as shown in the figure, the operator closes a tracking switch to begin the tracking operation. This consists of adjusting the position of the tracking line relative to the target image so that the two traces touch. The adjustment is made by means of a tracking control which corrects the setting of the closing-speed potentiometer.

As long as the tracking line coincides with the target image during the tracking operation, the computing circuits are provided with a voltage exactly proportional to the true closing speed. If the remaining terms of the range equation have been correctly set on the control unit, the voltage derived by the computer is then proportional to the correct slant release range for the conditions present. The slant

range voltage, when rectified in the synchronizer, provides a d-c control potential which determines the range position on the screen at which a release pip is generated. When the range represented by the tracking line coincides with the range at which the release pip occurs, the relays which control the release mechanism are energized and the bombs are dropped.

SLANT TRACKING RANGE SOLUTION.—The basis of the tracking solution in which the computer derives a voltage proportional to the slant distance from the plane to the target is illustrated in figure 9–6.

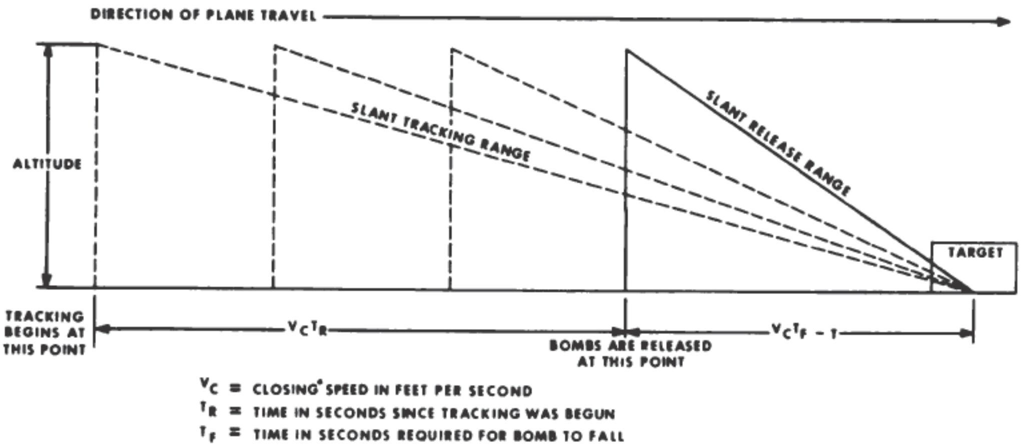


Figure 9–6.—Diagram of bombing problem.

The tracking triangles, shown in dotted lines, are solved for slant tracking range. The general procedure is the same used for the release triangle solution. A voltage taken from one of the phases of the two-phase computer generator is adjusted in amplitude so that it is proportional to the altitude of the aircraft. The other output of the generator, displaced by 90 degrees from the first, is adjusted so that it is proportional to the ground range distance from plane to target at any moment during the bombing run. The two voltages are applied to the input of the tracking mixer-amplifier, the output of which is then proportional to the slant range required. The voltage produced by the process is rectified in the synchronizer. The d-c potential resulting

is a control voltage which determines the position on the screen at which the tracking line appears.

As shown in figure 9–6, the ground-range distance forming the base of the tracking triangle is a decreasing quantity. Hence, the voltage which represents this distance in the vector addition must also decrease. The rate of decrease must be proportional to the closing speed of the aircraft as it approaches the target. To provide the changing voltage, two voltages which differ in phase by 180 degrees are combined. One is fixed in value and the other increases. When combined, these two give a voltage which constantly decreases and which represents the ground-range distance. The resultant produced by vector addition in the mixer-amplifier of the voltages shown in figure 9–7 is the decreasing slant tracking voltage.

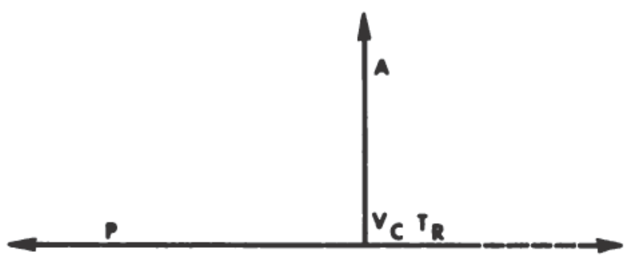


Figure 9–7.—Components of the slant tracking voltage.

One of the voltages forming the base of the vector diagram is called the LOCATOR potential and is labelled P. The other, $V_c t_r$, increases with time. In this component, V_c is proportional to the closing speed and t_r is the time elapsed since the start of tracking. The two voltages have the following meaning in the bombing problem:

1. The locator voltage is proportional to the ground distance between the plane and the target at the moment the tracking operation begins. This value is determined by means of the LOCATOR control which the operator adjusts prior to the start of the tracking operation in bringing the tracking line into contact with the target image.

2. The increasing range voltage, $V_c t_r$, is proportional to the product of a velocity and a time, and is therefore propor-

tional to a distance—the ground distance which the plane has passed over after the start of the tracking operation.

The difference in these two quantities, $P - V_c t_r$, is then proportional to the ground range separating the plane and the target at any moment during the tracking operation. When this quantity is added vectorially to the altitude component, the resultant is proportional to the slant tracking range at any moment during tracking.

One of the principal factors in the solution of the tracking problem is the range voltage, $V_c t_r$, which is proportional to the product of the closing speed and the elapsed tracking time. A method used to derive it is shown in simplified schematic form in figure 9–8.

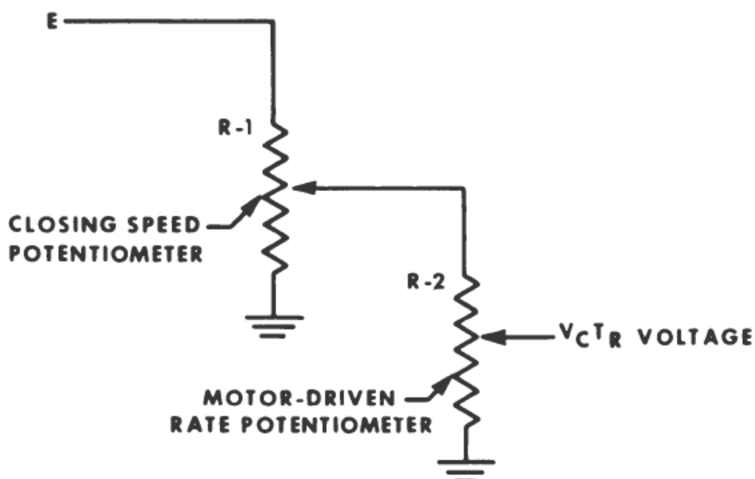


Figure 9–8.—Simplified range-voltage circuit.

A portion of the ground-phase voltage of the two-phase computer generator is applied across R–1, the closing-speed potentiometer. The sliding contact is adjusted during the bombing run (by matching the tracking and target traces) to derive a voltage which is proportional to the closing speed. This voltage is applied across R–2, a motor-driven rate potentiometer which supplies the time factor, t_r, in the required output voltage. At the moment tracking begins, the operator closes a switch which causes the motor to begin driving the sliding contact slowly up from the grounded end of R–2. As a result, the output voltage increases with time. The value of the output voltage depends at any moment on

the setting of the closing speed potentiometer and the elapsed time since the switch was closed at the start of the tracking operation, therefore the output in proportional to $V_c t_r$.

Collision Course Approach

The solution provided by radar bombing attachments for bombing problems involving the bearing of the target is the COLLISION COURSE APPROACH, a course which leads the aircraft directly over the target. The basis of the collision approach is a fact which is well known to seamen: if one ship sights another at a true bearing which does not vary as the two vessels proceed, some change must be made, either in course or in speed, if the two are to avoid a collision. In a similar way, the bombing run can be made on a course which passes over a moving target such as a ship if during the approach the plane proceeds so that the ship remains at a constant true bearing. For a true collision course approach, it is necessary that the target be kept at a true bearing which does not vary and not merely at a constant relative bearing.

During the bombing run the target is observed on the bombing scope which reproduces all the target data seen on the screen of the parent radar. On the bombing scope, the bearing of the target is represented by the horizontal position of the image with respect to a vertical center line inscribed on the screen. To allow the true bearing of the target to be observed, the bombing presentation is stabilized in azimuth. This means that the center line of the screen represents a fixed direction in space regardless of changes made in the heading of the plane within the limits of the stabilizing equipment. Stabilization is accomplished by the use of a gyro stabilizer, a device which is also employed in optical bombing devices. The effect produced by the stabilizer is shown in figure 9–9.

The stabilizer holds the presentation fixed over a range of about 30 degrees. For example, if the indicator center represents true north, as in figure 9–9, and the aircraft turns 15 degrees in either direction, the center of the indicator screen continues to represent north, and a target at

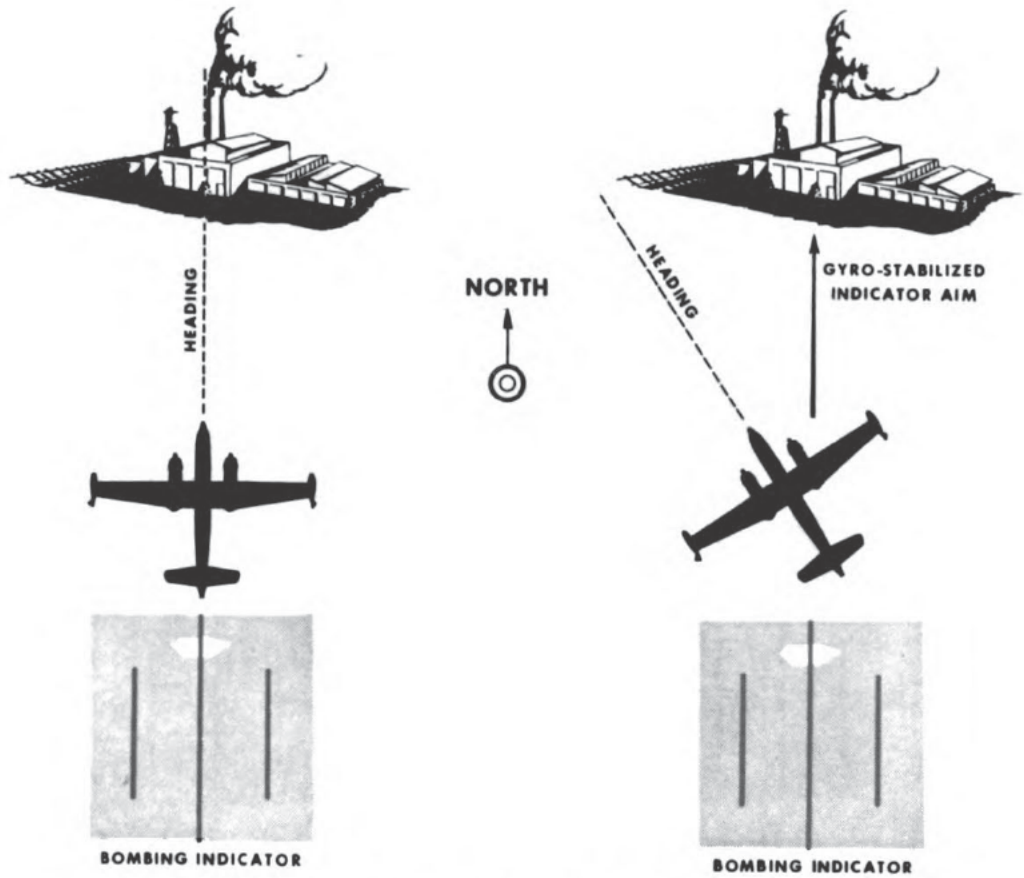


Figure 9–9.—Azimuth stabilization of the bombing indicator.

that bearing appears under the center line of the screen as before.

FLIGHT CONTROLS.—When the bombing run begins, the operator of the bombing attachment takes control of the heading of the aircraft. This is done either by means of a pilot direction indicator (PDI) or by the use of an automatic pilot system. The PDI is a zero-center voltmeter, the pointer of which is controlled by the operator and observed by the pilot. When the operator desires a turn, his control knobs move the pointer and the pilot makes the turn indicated. When the turn has been completed, the pointer of the PDI returns to the center position. When an automatic pilot is employed, the operator has direct control of the aircraft heading.

The operator actuates the PDI (or the automatic pilot) by means of two control knobs, the COURSE and DRIFT

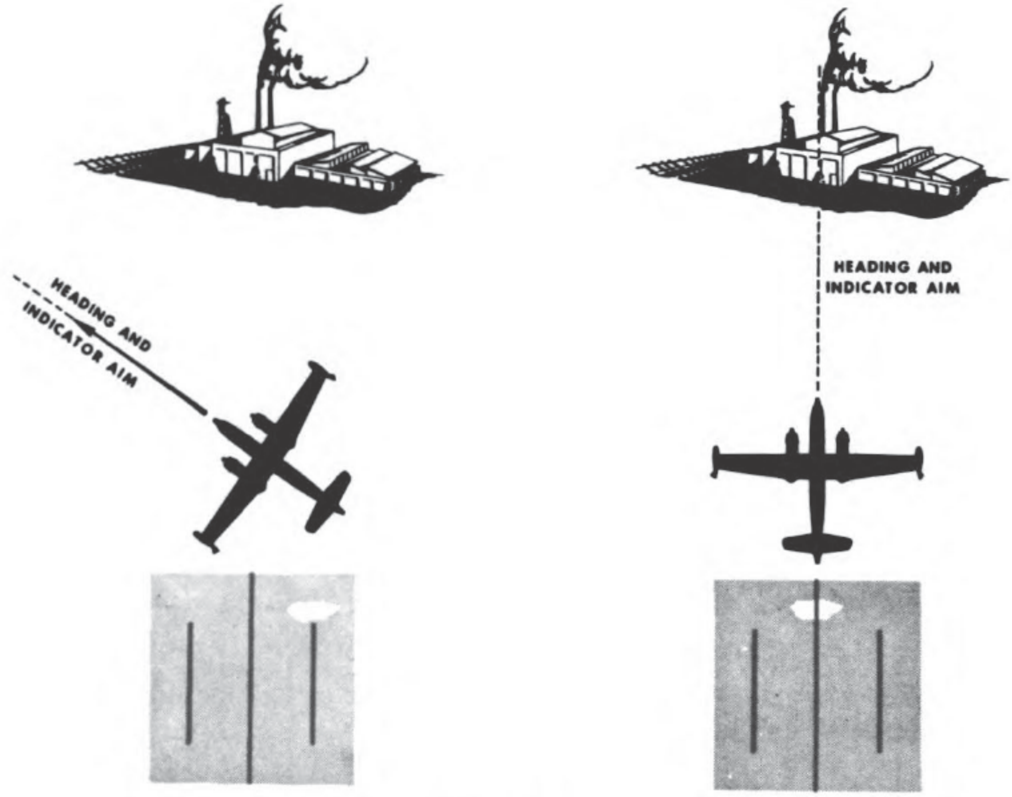


Figure 9–10.—Use of the course control.

controls. The course knob is used to aim the aircraft directly for a target. It does two things—it directs a turn and changes the direction, or aim, of the stabilized screen presentation, as illustrated in figure 9–10.

The result of using the course control alone is to turn both the nose of the plane and the indicator presentation by an equal amount. In the left-hand drawing of figure 9–10, the target appears on the bombing scope at about 15 degrees to starboard. The heading of the plane is then changed by rotating the course knob until the target lies dead ahead. In addition, the true bearing of the radar screen presentation is also changed 15 degrees so that the target is in the center of the screen.

The course knob provides sufficient control for attacking a stationary target when there is no cross wind. But when target motion and wind drift are present, the second control, the drift knob, is also required.

The drift control changes the heading of the plane through

the action of the PDI or the automatic pilot as does the course control; but unlike the course control, it does not affect the aim of the stabilized bombing screen. The purpose for which it is used is illustrated in figure 9–11.

Assume that the aircraft is approaching a stationary target in a cross wind as indicated in figure 9–11. The effect of the wind is to cause the plane to follow a course which is 15 degrees to the left, resulting in apparent motion of the target. To compensate, the aircraft is first aimed directly at the target by use of the course, or turn, knob as shown in the left-hand drawing. The heading of the aircraft and the direction of the stabilized indicator aim are now the same. If the aircraft should continue on this heading, however, it would be blown off course and would not pass over the target. As shown in the right-hand drawing, the drift control is used to turn the aircraft upwind so that the heading makes a drift angle of 15 degrees with the track. The

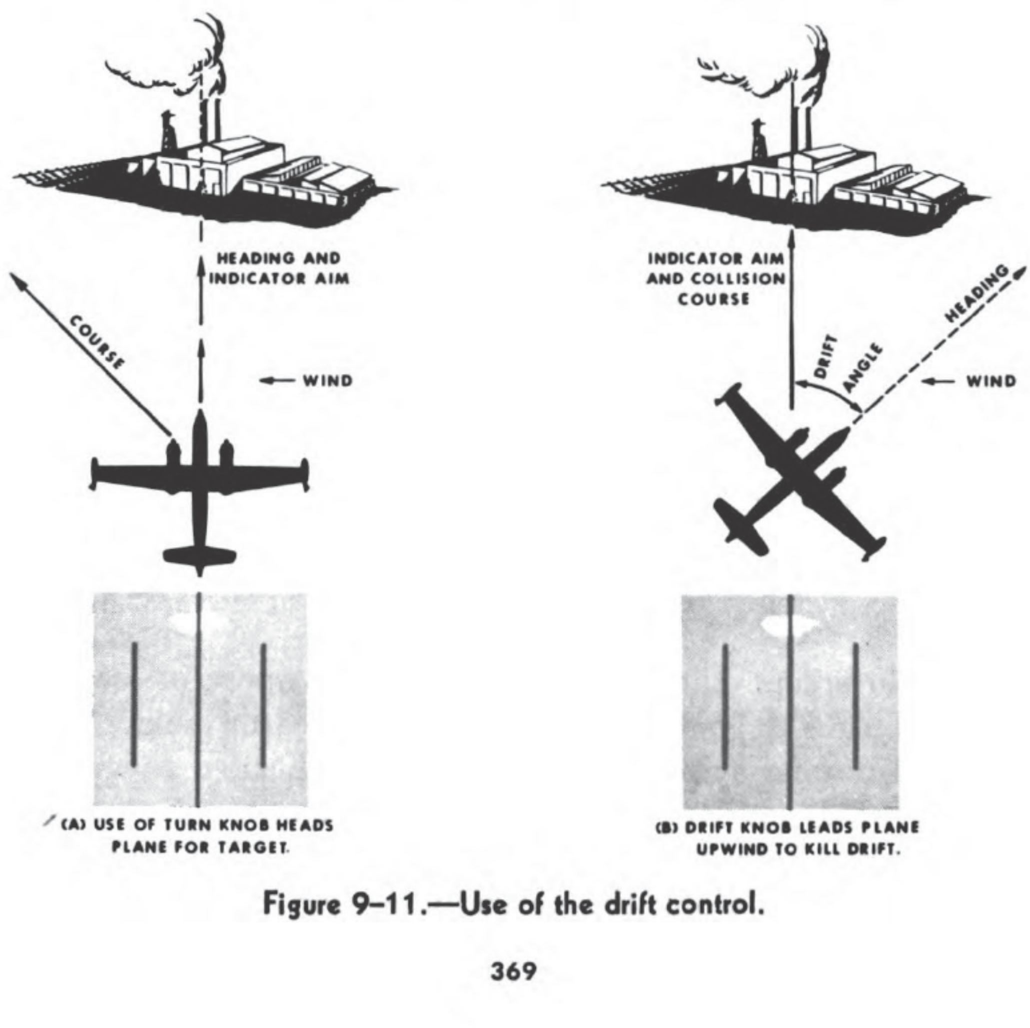


Figure 9–11.—Use of the drift control.

aim of the radar screen remains unchanged and the target image appears in the center of the display as before. If the drift angle is set correctly, the plane will travel directly over the target. During the approach, the desired course is indicated when the target image is centered on the screen. If it should deviate from this position, the operator adjusts the drift control until it is again centered.

The same solution is used for intercepting moving targets. In setting the collision course, it makes no difference whether the apparent drift is caused by target motion, by wind, or by a combination of both. An interception course is set up when the moving target remains at constant bearing to the aircraft. This is shown in figure 9–12 for a no-wind condition.

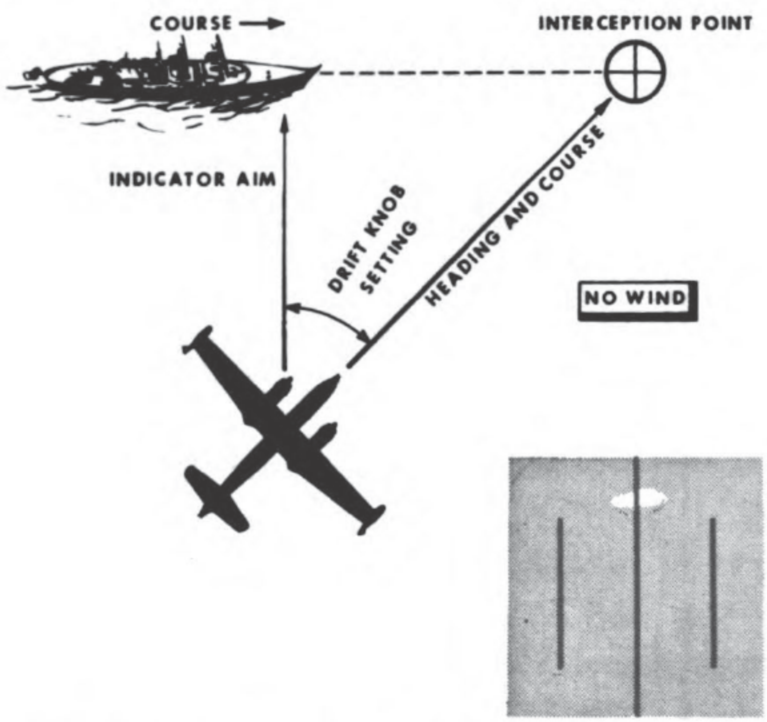


Figure 9–12.—Collision course with moving target.

To intercept the moving target, the operator uses the drift control to lead the target. The indicator looks directly at the moving ship while the aircraft is headed toward the interception point. The heading and course of the plane are adjusted during the bombing run so that the target image remains along the indicator center line. The use of

the drift knob allows adjustment of heading while maintaining the indicator aim constant. If the image moves away from the center of the screen, a collision course has not been set, and further adjustment must be made in the heading by the use of the drift knob.

QUIZ

1. The hypotenuse of the release triangle is called the
   a. ground release range
   b. release triangle minimum range
   c. release triangle maximum range
   d. slant release range

2. In a vacuum, the time of fall of a bomb depends on the
   a. forward speed imparted by the aircraft and the altitude from which the bomb is dropped
   b. altitude from which the bomb is dropped
   c. altitude from which the bomb is dropped, the drift angle, and the forward speed imparted by the aircraft
   d. forward speed imparted by the aircraft

3. What is the approximate acceleration of gravity in a vacuum?
   a. 16 ft. per second
   b. 32 ft. per second
   c. 32 ft. per second per second
   d. 16 ft. per second per second

4. One knot is equivalent to what number of feet per second?
   a. 1.69
   b. 101.3
   c. 60.8
   d. 6,080

5. An aircraft is flying at an altitude of 2,300 feet and a closing speed of 200 knots. Assuming a vacuum, what is the ground release range of a bomb in order to score a hit on a target?
   a. 2,000 ft.
   b. 1,600 ft.
   c. 338 ft.
   d. 4,056 ft.

6. How does air resistance affect a falling bomb?
   a. Vertical velocity and horizontal velocity both are decreased.
   b. Horizontal velocity only is decreased.
   c. No effect on either horizontal or vertical velocity.
   d. Vertical velocity only is decreased.

7. The horizontal distance astern of the aircraft at which the bomb strikes the earth when released in air is called
   a. horizontal range
   b. trail
   c. horizontal range plus trail
   d. horizontal range minus trail

8. The three factors which determine trail are
   a. airspeed, altitude, and wind
   b. altitude, wind, and bomb characteristics
   c. altitude, airspeed, and bomb characteristics
   d. airspeed, wind, and bomb characteristics

9. The time of fall for each type of bomb is printed in ballistic tables and usually is given in
   a. minutes and seconds
   b. minutes
   c. seconds
   d. microseconds

10. In bombing equations, trail is usually expressed in
    a. seconds
    b. yards
    c. minutes
    d. feet

11. In the operation of bombing attachments, the slant distance from plane to target is usually determined by
    a. radar plus a computer
    b. computer
    c. adding the ground release range and the trail
    d. subtracting the trail from the ground release range

12. Pertaining to an optical bombsight, the line of direction which the telescope makes with the vertical is called the
    a. trajectory angle
    b. drift angle
    c. trail angle
    d. sighting angle

13. In bombing calculations, target motion is usually considered as equivalent to which of the following?
    a. Drift
    b. Time of fall
    c. Trail
    d. Apparent wind

14. The reference range marker on a radar bombing attachment is called
    a. lubber line
    b. tracking line
    c. range computer
    d. plotter

15. Which unit of a typical radar bombing attachment supplies the pulse that determines the time when the bombs are released?
    a. Indicator assembly
    b. Gyro stabilizer
    c. Synchronizer
    d. Control unit

16. The bombs are automatically dropped by the radar bombing attachment when slant tracking range
    a. equals slant release range
    b. is less than slant release range
    c. is more than slant release range
    d. increases and slant release range decreases

17. The information required for setting the altitude value of the computer is supplied by the
    a. indicator assembly
    b. control unit
    c. synchronizer
    d. altimeter of the aircraft

18. The information required for making the closing-speed adjustments on a bombing run is supplied by the
    a. synchronizer unit
    b. control unit
    c. radar screen on indicator assembly unit
    d. radar screen on search radar set

19. Target range on a type-B scan is measured by distance from
    a. lower side of screen
    b. top side of screen
    c. center of screen
    d. side to side

20. The operator of a typical radar bombing attachment performs which of the following actions when he uses the "locator" control?
    a. Locates the target to be bombed
    b. Positions the tracking line on the indicator screen
    c. Computes the time of fall of the bombs
    d. Computes the trail angle

21. What type of voltage represents the ground-range distance of the tracking triangle?
    a. Decreasing d. c.
    b. Increasing d. c.
    c. Increasing a. c.
    d. Decreasing a. c.

22. What type of voltage is the slant tracking voltage?
    a. Decreasing d. c.
    b. Increasing d. c.
    c. Increasing a. c.
    d. Decreasing a. c.

23. In order to have a true collision course approach, the target must be kept at a
    a. constant true heading
    b. relative bearing
    c. constant true bearing
    d. magnetic heading

24. During the bombing run approach, the desired course is indicated when the target image is
    a. not present on the indicator screen
    b. left-of-center on the indicator screen
    c. right-of-center on the indicator screen
    d. centered on the indicator screen

25. To intercept a moving target, the operator uses the drift control to
    a. lead the target
    b. trail the target
    c. bear to the right of the target
    d. bear to the left of the target

CHAPTER 10

AIRBORNE EQUIPMENT FOR ELECTRONIC COUNTERMEASURES

It is the purpose of this chapter to introduce the general principles involved in the operation of electronic countermeasures devices. In the discussion which follows, certain specific examples of countermeasures equipments are described to illustrate these principles. Because of security reasons, the choice of equipments for this purpose is limited, and the examples given are somewhat older than many in current use. The descriptions of the units included here are not intended to provide detailed information concerning maintenance and operation, but are given solely to present the broad basic facts which are common to many examples of countermeasures equipments, both old and new. No information is included which relates to such equipments as the AN/APR–9 and AN/APR–13 receivers, the AN/APA–74 analyzer, the AN/ALR–3 receiver, the AN/ALT–2 and AN/APA–69 direction finders, and other newer ECM devices. Readers in search of material pertaining to the circuitry, maintenance, and operation of these and similar equipments are referred to the appropriate classified publications.

It is a basic rule of warfare that for each weapon used by the enemy, a counterweapon must be developed. This rule is clearly expressed in modern war by the development and use of electronic countermeasures (ECM). The counterweapon in this case is used against enemy electronic equipment—against radar, communication transmitters and

receivers, navigation aids, and electronically controlled weapons (such as guided missiles and proximity fuzes). The objective of ECM is to make the enemy's use of these electronic devices ineffective and to obstruct his profitable employment of the electromagnetic spectrum.

Electronic countermeasures consist of two general types of actions: passive and active. Passive ECM are operations which cannot be directly detected by the enemy, for example, reconnaissance or search operations, in which enemy transmitters are detected and located and as many as possible of the signal characteristics are determined. Passive countermeasures also include evasive tactics taken to avoid detection, and methods of controlling the radiations from friendly equipments to prevent the enemy from using the signals for homing, direction-finding, or for any other purpose.

Active ECM are actions which can be detected by the enemy and which prevent him from making effective use of his equipment. In the active phase, jamming transmitters are used to produce interference with radar and communications reception so that enemy receivers are subjected to obscuring and confusing radiations. In active radar countermeasures, jamming is often accomplished by the use of strips of metallic foil released from aircraft (and sometimes fired in projectiles). The falling strips intercept radar waves and reradiate them, causing numerous false targets to appear on the radarscope so that the enemy operator is unable to detect desirable targets and fire control radar is unable to see attacking planes.

Before active countermeasures can be undertaken, an extensive search, or intercept, campaign must be made to learn what types of electronic equipment are in active enemy use and the purposes for which they are employed. To gain this information, intercept flights are made in aircraft which carry special ECM equipment. With the equipment, the ECM operator tunes in signals from enemy units and measures their characteristics. He records the results in a log which is later submitted to tactical officers for analysis and evaluation. The information gained is

then used in planning active countermeasures, such as jamming, for directing control of radiation from friendly units, and for devising means for evading detection by the enemy equipments reported.

The principal kind of ECM equipment used in collecting these data are:

1. Search receivers, which are designed for intercepting signals occurring throughout wide ranges of frequency. Two general types are used—those with narrow bandpass characteristics and those with wide bandpass. Narrowband receivers are usually equipped with several plug-in tuning units, each of which can be either manually tuned or automatically swept over a selected frequency sector by motor-driven tuning circuits. Some types of broadband receivers are untuned so that signals are received simultaneously over a wide frequency range. In others, rapid automatic tuning is used.

2. Antennas. ECM antennas are broadband devices which respond to a very wide range of frequencies without excessive tuning adjustment. In many of the units, the assembly includes built-in impedance-matching sections.

3. Panoramic adapters, which are used as attachments for the search receiver. The adapter supplies visual indications of all signals present in selected frequency ranges and reveals the types of modulation and frequency of the signals intercepted.

4. Pulse analyzers. These units are used for measuring the characteristics of pulsed emissions, and in some cases give visual indications of such properties as relative signal strength and pulse shape.

5. Direction finders are used to determine the relative bearing of a given signal source and to assist in locating enemy transmitters. In many ECM direction finders, cathode-ray tubes are used as indicators which enable the operator to distinguish the types of signals received and to detect characteristics such as lobe switching in fire control radar units.

6. Recorders. Tape recorders are used to make records of the signals received by the associated search receiver as it

is tuned rapidly through the spectrum. The recording, which is analyzed after the flight, gives information concerning the frequencies of the signals, the amplitude, and the time of reception.

7. CATHODE-RAY OSCILLOSCOPES and AUDIO OSCILLATORS are sometimes used to measure the repetition frequencies of radar pulses when a pulse analyzer is not available. The pulse repetition frequency is determined from the patterns which result from application of the received signal to the vertical deflection plates of the scope while sweeping the beam horizontally with the output of the calibrated audio oscillator.

The information derived with these various types of search equipment consists of the characteristics of the enemy signals. These properties form the basis for estimating the capabilities and weaknesses of the electronic installations and for devising effective jamming techniques to be used against them.

SIGNAL CHARACTERISTICS

To prepare effective countermeasures against communication systems and navigation aids, information is needed concerning the frequencies of the emissions, the types of modulation used, the polarization of the transmitted waves, and the exact locations of the stations. For countermeasures against enemy radar, much more information is required. The principal signal characteristics of importance are the carrier frequency, the pulse repetition frequency, and the pulse width. In addition, other data are very desirable. These include the peak output power of the transmitter, the type of scan employed, the rate of scan, the beam width, and the polarization of the antenna.

The CARRIER FREQUENCY is the starting point from which the other signal characteristics are determined. Knowledge of the frequency is necessary for determining the type of the radar and its probable function and for preparing effective jamming operations.

The second most distinguishing characteristic of the radar is its PULSE REPETITION FREQUENCY (PRF), or the number

of pulses emitted per second. The PRF value is a factor in determining the maximum range of the unit since it governs the time interval between the pulses. Long-range air search radars must necessarily use low PRF values, since the pulses need to be spaced at intervals sufficient to allow echo signals to return from the most distant object within the desired range. Higher values of PRF are used in surface-search radars designed for detecting objects at shorter ranges; while extremely high pulse rates are employed in such equipment as fire control radars which have very short range but extreme accuracy.

It is desirable to know the PULSE WIDTH of radar signals since this value is the basis for estimating the minimum range of the unit. Pulse width is the interval of time during which the magnetron is energized, and as a result, determines the shortest range at which objects can be received. In general, the longer the pulse width, the greater is the minimum range of the radar.

A rough estimate of the PEAK POWER of enemy radars can be made by an experienced ECM operator by observing the indications of relative signal strength of the intercepted pulses. The peak power employed is a clue to the purpose of the equipment in that long-range search units require large amounts of peak power while short-range sets demand lesser amounts.

The TYPE OF SCAN, the method by which the radar beam searches the target area, is a good indication of the nature and action of the radar. Types of scan include 360-degree and sector sweeps, lobe-switching, conical, and spiral scans. The simplest way of distinguishing the scan type is by listening to the intercepted signals. Signals from search radars usually cause a whine in the headphones, the tone being produced by the constant pulse rate. In 360-degree scan, the signal strength varies periodically as the beam sweeps over the search plane. So long as the signal variations continue, the radar is searching; but if the sound becomes loud and steady, the indication is that the set has probably detected the search plane and is concentrating its attention on it. Fire control radars often use LOBE SWITCHING in which the

beam looks first to one side and then to the other of the target. The shifting of the beam takes place rapidly and brackets the target while the radar compares the echoes from each beam position. Lobe switching is easily detected by visual indications of the signals on panoramic adapters, pulse analyzers, and direction finders. It also causes a characteristic chatter in the headphones as the beam position varies.

The RATE OF SCAN, or number of scanning sweeps made per minute, is related to the probable maximum range of the radar. Slow scanning is characteristic of long-range search sets, while short-range radars and fire control systems employ much higher scan rates. The rate is usually measured in terms of the time required for one scan. The signals are observed on the screen of a panoramic adapter or the scope of a direction finder. The operator logs the time interval between successive indications of maximum signal strength.

The measure of the BEAM WIDTH gives an indication of the azimuth accuracy of the enemy set. The width of the beam, which is expressed by the number of degrees between the half-power points, is generally computed from data provided by automatic recorders which give information concerning the amplitude of the signals.

The POLARIZATION of the radar antenna is considered in planning effective methods of jamming. This characteristic can be determined by the use of direction finders of the type which makes a visual display of the reception. The direction finder is equipped with two antennas—one polarized horizontally and the other vertically. Either antenna can be used for reception, and the polarization of the incoming signals is learned by comparing the patterns resulting from each.

A rough determination of polarization can be made by alternate shifting from vertical to horizontal receiving antennas. The antenna which is of proper polarization for the signal being received will provide an audible (panoramic) response indicating greater signal strength. Circular polarization will give approximately a uniform response on either antenna.

PASSIVE ECM EQUIPMENT

Search Receivers

The success or failure of an intercept mission depends largely on the proper functioning of the search receiver, the basic type of passive countermeasures equipment. By means of the receiver, the ECM operator detects the presence of radar and radio emissions, monitors enemy transmissions, learns the types of modulation used, and is given indications of relative signal strength.

When searching for enemy radar locations, the ECM receiver operates at a fundamental advantage with respect to the radar so that reconnaissance can be carried out without fear of detection by the enemy unit. Radar detects objects by reflection, or two-way transmission, in which the reduction of signal strength is proportional to the fourth power of the distance covered by the waves. The receiver, on the other hand, detects the radar by a one-way transmission in which signal reduction is proportional only to the square of the distance. As a result, the presence of the radar can be detected at a distance greater than the maximum range at which the radar can detect the search plane.

Search receivers are either untuned crystal detectors which accept all signals in a wide frequency range, or else they are superheterodyne circuits that can be tuned rapidly over various bands. In the latter type, the extremely wide frequency coverage required is provided by the use of several plug-in tuning units, each of which covers a part of the total tuning range of the receiver. Tuning units usually consist of a tuned antenna circuit, a local oscillator, and a mixer stage. The receiver produces three types of output—intermediate-frequency voltages for use in a panoramic adapter, video signals which are applied to a pulse analyzer, and an audio output for the headphones.

In figure 10–1, a typical ECM superheterodyne receiver is shown in block diagram form. The receiver (AN/APR–4) covers a tuning range from 38 to 4,000 megacycles and employs four tuning units.

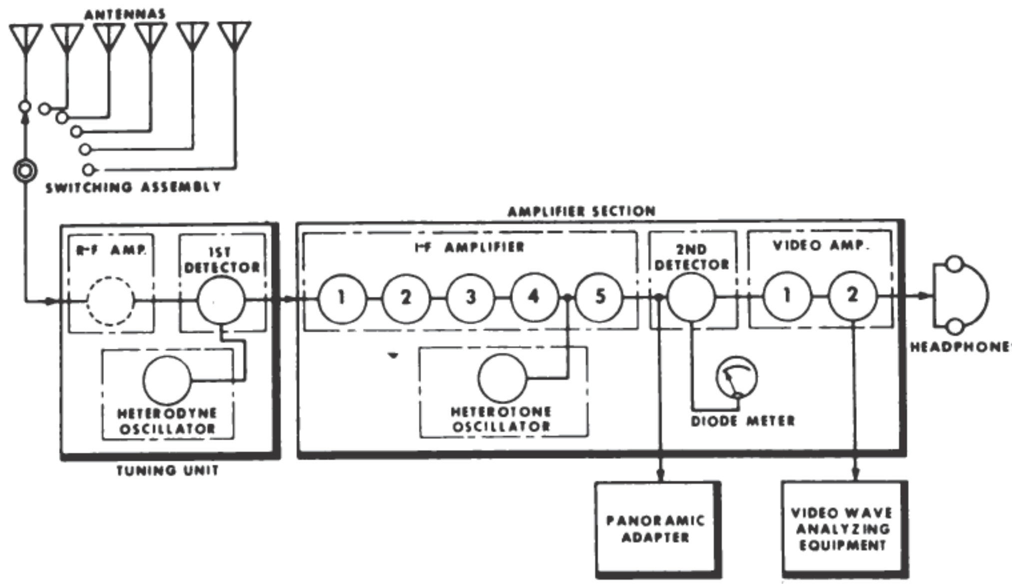


Figure 10-1.—Block diagram of ECM receiver.

Signals intercepted by the antenna in use are fed to a connection on the receiver through a switching assembly which enables the operator to select the proper antenna for the frequency range to be covered. From the antenna connection, the incoming signals are applied to one of the four plug-in tuning units. The low-frequency unit contains a wave trap tuned to the intermediate frequency of the receiver and is used to suppress undesired reception. This tuning unit also contains one stage of r-f amplification. In the three higher frequency units, no r-f amplification is employed and the signals are coupled from the antenna to the input of the first detector. Mixing of the signal with the output of the local oscillator produces an i-f output of 30 megacycles. Five stages of i-f amplification are provided; the output of the last stage is applied to a connection on the front panel to which a panoramic adapter can be attached. The output of a beat frequency oscillator (heterotone oscillator) is applied to the last i-f amplifier for detecting c-w emissions. A portion of the amplified i-f output is rectified in a diode and applied to a d-c microammeter which gives an indication of the relative signal strength. The 30-mc. i-f output is demodulated in a second detector stage which also provides avc voltages. Following the second detector are two stages

of video amplification which supply signals for the headphones and also to a video connection on the front panel to which a pulse analyzer can be attached.

Receiver tuning units.—The tuning units used in the receiver shown in figure 10–1 are slide-in assemblies which fit into a receptacle in the main receiver unit. Each tuning section contains a sweep motor equipped with a reversing switch to provide automatic coverage of the frequency range. In addition, a dial is included for manual tuning adjustments. The automatic tuning system allows sector sweep operation in which the motor tunes the receiver over all the band or any portion of it. The motor, acting through a magnetic clutch, drives the tuning capacitors periodically through the frequency sector selected. When the capacitors, and also the frequency dial, have rotated to the end of the sector, the reversing switch is actuated and the rotation of the motor is reversed in direction. The speed of rotation and hence the rate of tuning can be controlled by the operator.

A schematic diagram of one of the tuning units is shown in figure 10–2. The unit illustrated is designed for operation in the range from 80 to 300 megacycles.

The unit contains a local oscillator and a diode mixer. The antenna is coupled to the mixer tank circuit, and incoming signals are mixed with the output of the local oscillator which operates at frequencies from 110 to 330 megacycles. The i-f signals at a frequency of 30 mc. are developed

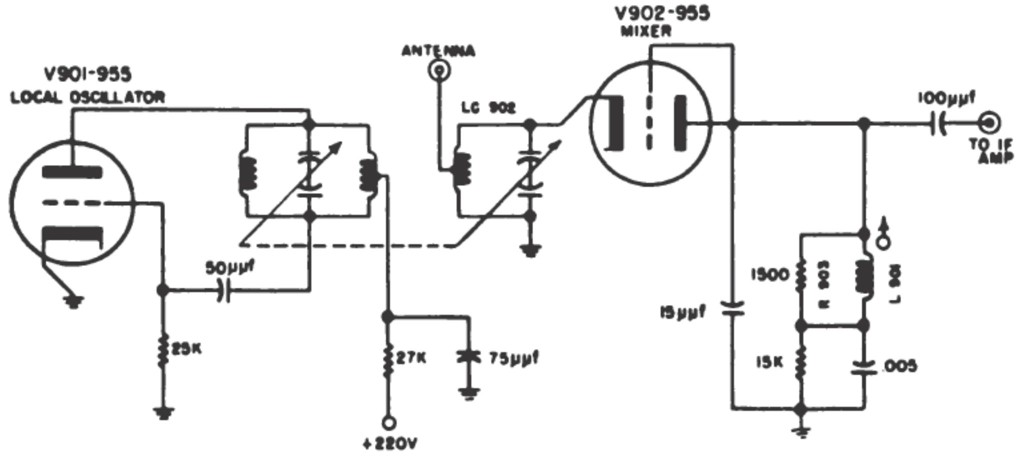


Figure 10–2.—Tuning unit of ECM receiver.

across the resonant circuit consisting of inductor L901 and the shunt capacitance of the mixer tube. A 15,000-ohm resistor in parallel with a 0.005-mfd. capacitor is used to produce a biasing voltage on the plate of the mixer diode so as to reduce the loading effect of the tube on the output tuning circuit.

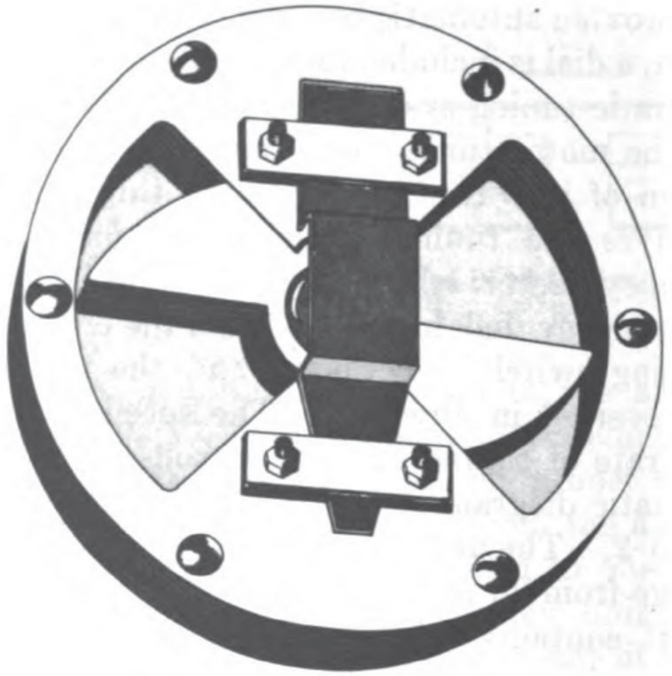


Figure 10–3.—Butterfly tuner.

A butterfly tank circuit is used in the local oscillator and another in the mixer, or first detector, of the tuning unit shown in figure 10–2. Butterfly tuners are frequency-determining circuits in which both inductance and capacitance are provided by a fairly simple structure arranged so that both can be varied simultaneously without the use of sliding contacts. These tuners are often used in ultrahigh-frequency oscillators and are well adapted for circuits which generate small amounts of power over wide ranges of frequency. The name of the device was suggested by the appearance of the rotor plates, which in some models resemble the opened wings of a butterfly. This type of tuning circuit is satisfactory for operation up to frequencies of 1,000 megacycles. In tuning units designed for frequencies above this

value, cavity resonators are usually employed for tuning and crystal rectifiers are used instead of vacuum-tube mixers. A butterfly tuner similar to the component used in the oscillator of the tuning unit illustrated in the figure above is shown in figure 10–3.

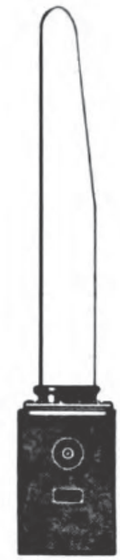
The inductance of the tuner is produced by magnetic flux lines encircling the outer rim of the stator plates of the variable capacitor. The circuit shown is equivalent to two single-turn coils connected in parallel with the split-stator capacitor. The plate of the oscillator tube is connected to one of the wedge-shaped sections of the stator and the oscillator grid is connected through a blocking capacitor to the other section.

SEARCH ANTENNAS.—Since enemy signals may appear over very wide ranges of frequency, the antennas used with ECM search receivers must necessarily be very broad in frequency response. To insure this, the antennas are made thick and stubby in structure so that the inductance value is low. As a result, the antenna stores very small amounts of energy and has a low Q with the broad frequency response which is characteristic of all low-Q circuits.

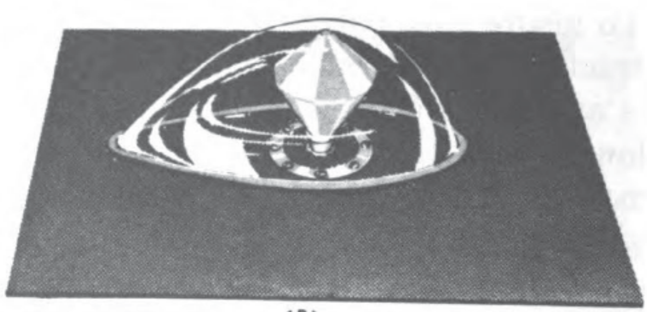
Two types of ECM antennas used with airborne search receivers are shown in figure 10–4.

The stub antenna, shown in (A), consists of a wooden mast about 22.5 inches in length which is covered with a thick metal plating. The plated area is connected to a receptacle for attachment to a 50-ohm coaxial cable. In (B) a cone antenna is shown which is designed for the frequency range of 300 to 1,000 megacycles. The reception pattern of the antenna shows uniform response in all directions perpendicular to the axis of the cone. The unit can be mounted either vertically or horizontally for reception of waves of either vertical or horizontal polarization. For reception of both types of waves, the cone is mounted at an angle of 45 degrees from the vertical.

Many types of ECM antennas other than the two illustrated are used in airborne installations. Usually the plane carries two of each type employed with one mounted on the



(A)



(B)

Figure 10–4.—(A) Stub antenna; (B) cone antenna.

port side and the other on the starboard. Selection of the appropriate antenna is made by means of a switch.

WAVE TRAPS.—Search receivers of the superheterodyne type often produce spurious responses caused by image reception in which a station is received at two different positions of the tuning dial. A second type of spurious response also frequently occurs which is caused by harmonics of the local oscillator. These beat with strong signals at frequencies other than that indicated by the dial and produce the intermediate frequency with the result that the stations are heard in the output. Since one of the primary functions of the receiver is to enable the operator to determine the frequency of an intercepted signal by means of the dial

reading, some device is needed to assist him in distinguishing true signals from spurious responses. For this purpose, wave traps, or tunable filters, are often used in conjunction with these receivers. The wave trap has a dial calibrated in frequency and can be switched into or out of the antenna lead-in. When the trap is in the circuit and tuned to the frequency of an incoming signal, the signal is filtered out and disappears from the output. By means of the calibration on the wave trap, the operator can decide whether or not the signal frequency is actually that indicated by the dial reading at which he receives it.

Panoramic Adapters

Panoramic adapters are specialized superheterodyne receivers. They are used for monitoring a wide range of frequencies and provide visual displays of the signals intercepted by the search receiver. The signal indications appear on the screen of a cathode-ray tube. The station to which the search receiver is tuned appears as an inverted-V deflection at the center of the screen; and signals above and below this frequency show similar deflections to the right or left of center depending on their values. The amplitude of any deflection is determined by the strength of the corresponding signal, so that the panoramic screen is a graph of signal intensity versus frequency. (Signal intensity is indicated on the vertical axis, and relative frequency is represented on the horizontal.)

In search operations, the panoramic adapter is used principally as a tuning aid since the presence of many stations is indicated simultaneously. It can also be used to determine the types of modulation of intercepted signals and for observing the effects of one's own jamming emissions.

Figure 10–5 is a block diagram of an airborne panoramic adapter. As shown in the figure, the device is a superheterodyne receiver with a special sort of local oscillator. The input to the adapter consists of i-f signals from the ECM search receiver, application being made through a large isolation resistor and blocking resistor so that the

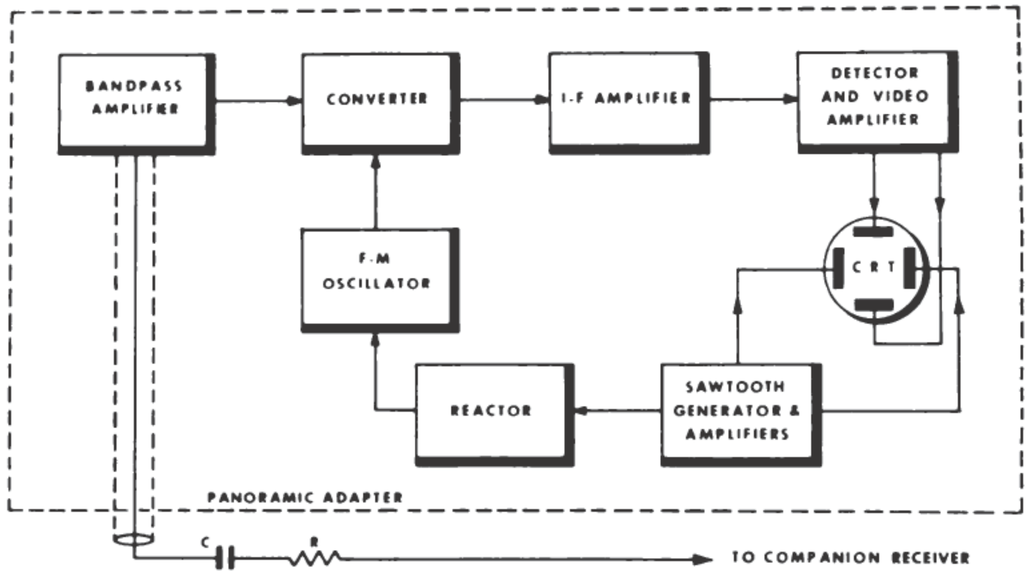


Figure 10–5.—Block diagram of panoramic adapter.

operation of the receiver is unaffected. As a result, the operator can listen to the signal to which the search receiver is tuned while observing signals above and below this frequency over a total range of 10 megacycles.

The adapter input stage is an r-f bandpass amplifier. The frequency characteristics of this circuit are such that signals given low amplification in the i-f section of the associated receiver are emphasized, and the overall response curve is flat over a range of about 10 megacycles. The midfrequency of this range is 30 mc., the i-f of the search receiver; and all signals from 5 mc. below the station to which the receiver is tuned to 5 mc. above are passed simultaneously.

The signals received simultaneously are then separated on a time basis so that each is presented on the screen at a slightly different time. This is accomplished by the action of the converter, the f-m oscillator, and the i-f amplifier which is sharply tuned to 6.5 mc. The output of the f-m oscillator varies in frequency over a 10-mc. range with an average value which is 6.5 mc. below the midfrequency of the band of incoming signals. As the oscillator sweeps through its range, beat frequencies are produced with all signals in the converter. But at any given instant, the difference frequency of 6.5 mc. is produced with only one signal, while

beats different from 6.5 mc. are produced with all the remainder. Since the following i-f amplifier is sharply tuned to 6.5 mc., it passes the signals one at a time.

The amplified output is demodulated in a detector and the resulting video pulses are then applied to the vertical plates of the indicator tube through a video amplifier.

The frequency of the f-m oscillator is varied periodically by means of a reactor, or reactance tube. The reactor is a pentode connected so that variations in the grid voltage (and hence the plate current) lag any variations in the plate voltage by 90 degrees. As a result, the phase relation of voltage and current in the plate circuit is similar to that of an ordinary inductance coil. The plate circuit of the reactor is connected in parallel with the tuning tank of the oscillator and the tube has the effect of a shunt coil. The value of the apparent inductance of the reactor is varied by means of a sawtooth voltage so that the frequency of the local oscillator is swept over the desired range.

The sawtooth generator which controls the reactor also applies a similar sawtooth wave to the deflection plates of the cathode-ray tube so that the oscillator sweep and the movement of the electron beam in the C–R tube are synchronized, each making 30 sweeps per second.

A switch is provided for disconnecting the reactor tube so that the local oscillator is allowed to operate continuously at its average frequency of 6.5 mc. below the incoming signal frequency. In this mode of operation, the instrument functions as an ordinary oscilloscope and can be used to measure pulse repetition frequencies of intercepted radar signals.

INTERPRETATION OF PATTERNS.—Since a comparatively large number of signals may be observed simultaneously on the screen of the panoramic adapter, the instrument has great value in detecting enemy transmissions. Furthermore, the experienced operator can obtain additional information concerning the nature of the transmissions by inspection of the patterns. The oscillograms produced by several types of signals are shown in figure 10–6.

A constant carrier appears as a deflection with fixed

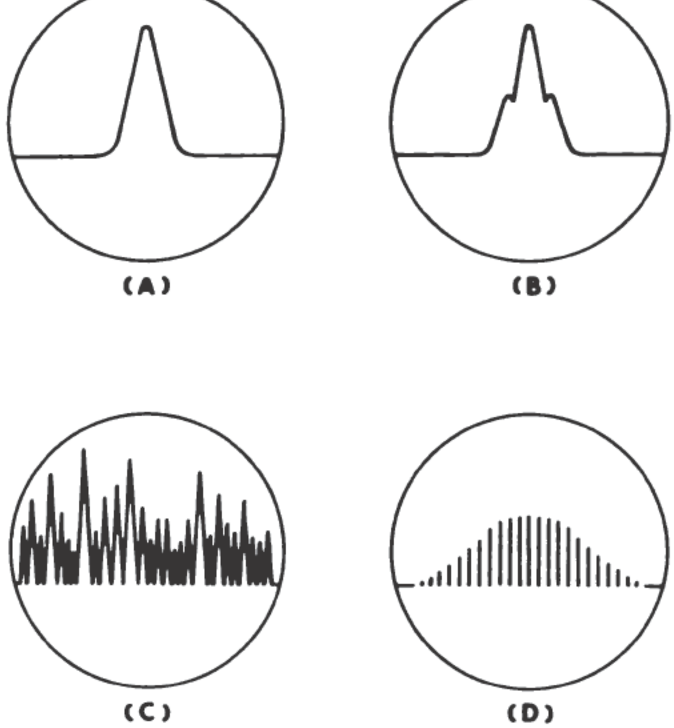


Figure 10–6.—Panoramic adapter patterns.

height as shown in (A) of the figure. Amplitude-modulated carriers appear as deflections which vary in height. If the modulating frequency is high, the sideband frequencies appear separately causing pips on either side of the carrier deflection. Modulation with a single audio tone produces the pattern shown in (B) of the figure. A frequency-modulated carrier appears to wobble sideways. When the carrier is frequency modulated by voice or music, the appearance is a number of deflections which spread across a variable band as in (C) of figure 10–6. Pulse modulation gives the pattern shown in (D) of the figure when the pulse repetition frequency is considerably greater than the rate of sweep of the indicator beam.

A c-w signal appears and disappears with the keying of the transmitter. Two signals which are near enough in frequency to produce an audible beat note appear on the screen as a single carrier which varies in amplitude at the beat frequency. Noise voltages which vary regularly produce deflections which move across the screen in either direction—

the motion being caused by the fact that the noise pulses are not synchronized with the panoramic sweep. Noise and interference such as static bursts which are not periodic produce irregular deflections and flashes along the length of the screen.

If image reception takes place in the associated receiver, the image signal has the same sort of appearance as the true signal. However, when the receiver tuning dial is rotated, the image pip moves in the opposite direction to that of the true signal deflection.

Pulse Analyzers

Pulse analyzers are used in ECM operations for measurement of the pulse repetition frequencies and pulse widths of radar signals detected by search receivers. The analyzer can also supply information concerning lobe switching, rotation rates, and beam widths of radar transmissions. In many pulse analyzers, the data are presented visually by means of cathode-ray tubes, although in some the pulse width and PRF values are indicated on meters. An example of the type using a cathode-ray tube as an indicator is shown in block diagram form in figure 10–7. The equipment shown, AN/APA–11, was designed for airborne applications and is used with several types of ECM search receivers.

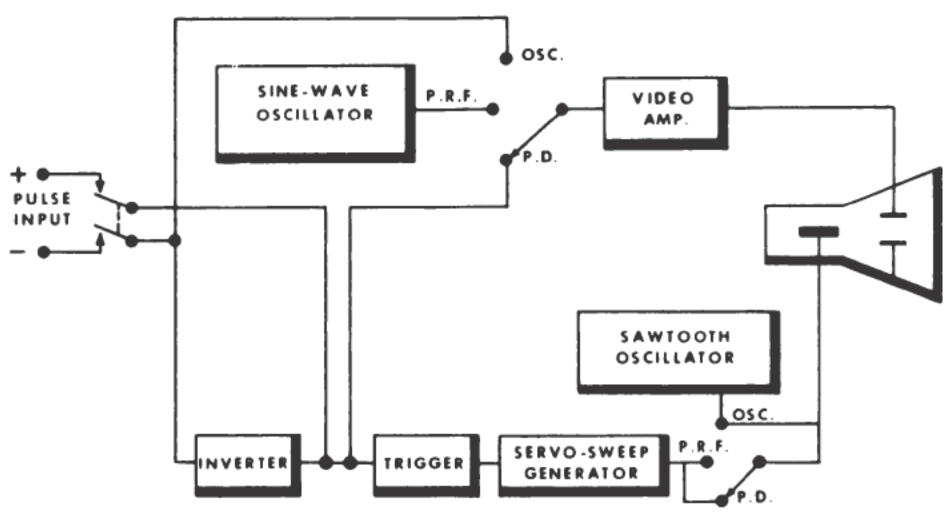


Figure 10–7.—Pulse analyzer block diagram.

The equipment illustrated has three basic functions: pulse width measurement, pulse-repetition-frequency measurement, and operation as an airborne oscilloscope. One of the three functions is selected by means of a switch on the control panel. In the PD (pulse duration) and PRF positions of the switch, the horizontal sweep voltage for the cathode-ray tube is provided by a servo-sweep generator which deflects the electron beam only when incoming radar pulses are applied. The pulses are supplied by the associated search receiver; these initiate the action of the sweep generator which provides three sweep speeds for measuring pulse widths in the ranges 0–8, 0–40, and 0–160 microseconds.

When the equipment is operated as an oscilloscope, the horizontal sweep is provided by the output of a free-running, sawtooth oscillator which gives a continuous sweep as in ordinary oscilloscopes.

The pulses to be analyzed may be either positive or negative depending on the receiver in use. As shown in figure 10–7, two input connections are provided through which the signals may be applied.

Negative signal pulses are conducted by the trigger amplifier section through an inverter stage which reverses the polarity, while positive pulses do not pass through the inverter.

The trigger amplifier contains two stages of amplification which increase the intensity of the signals and apply them to the servo-sweep section. This system contains a flip-flop circuit, or single-kick multivibrator, which produces one rectangular pulse each time an incoming signal pulse is applied. The rectangular pulse from the flip-flop circuit is used to control the action of a vacuum-tube sweep generator and also to unblank the cathode-ray tube. The rectangular pulses from the multivibrator bias the grid of the sweep tube to cutoff and allow its plate voltage to rise. The resulting plate variation is impressed across the horizontal deflection plates of the indicator tube to produce the horizontal sweep.

Some of the typical patterns which appear on the indicator screen of this type of pulse analyzer are shown in figure 10–8. In (A) and (B) the traces represent a radar signal which is

being measured for pulse width, or duration. In (C) the pattern employed in PRF determination is shown, and in (D) the display represents the pulses from a radar which is lobe switching.

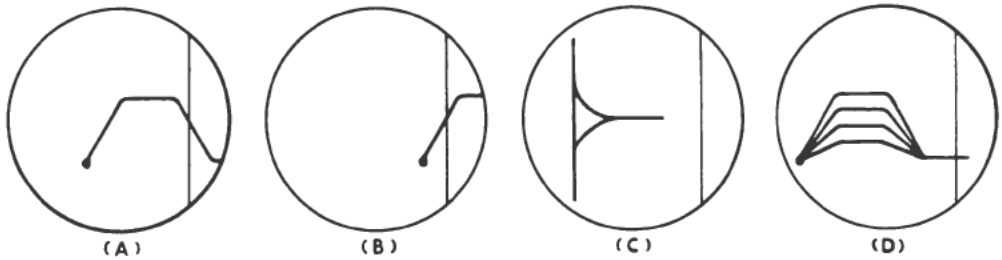


Figure 10–8.—Pulse analyzer indicator patterns.

For pulse width measurement the radar signals are applied to the vertical deflection plates of the cathode-ray tube of the analyzer; and since one horizontal sweep occurs for each pulse, the waveform of the pulsed signal is traced on the screen as a single pattern similar to that shown in (A) of the figure. The horizontal position of the pattern on the screen can be shifted by means of a PULSE DURATION dial which is calibrated in microseconds. In the first step of the measurement the pattern is adjusted with a video gain control so that it is from ¼ to ¾ inches in height. The pulse duration control is used to place the waveform so that the vertical index marker on the scope intersects the right, or trailing, edge at about 70 percent of the peak amplitude. The dial reading for this position is noted. The pattern is then shifted with the duration control until the index line falls on the leading, or left, edge of the pulse as shown in (B) of the figure. The difference in the dial readings for the two positions is the pulse duration in microseconds.

In measuring PRF, patterns similar to that shown in (C) of figure 10–8 are produced by applying the output of a resistance-coupled, sine-wave oscillator to the vertical deflection plates of the indicator tube. When no pulse signals are present in the analyzer, the trace is a single vertical line. Upon application of radar pulses, the beam is swept horizontally, making one deflection for each signal pulse. The

frequency at which the sine-wave oscillator sweeps the beam vertically is controlled by means of two calibrated dials on the front panel of the instrument, and the PRF is determined from the dial readings. The sine-wave output is adjusted to the lowest frequency which will cause a pattern consisting of one stationary horizontal trace to appear. The PRF of the incoming signal is then equal to the frequency of the internal oscillator as indicated on the control dials. (It is important that the lowest frequency of the sweep oscillator be selected since single traces result if the sine-wave frequency is greater than the PRF by a whole multiple.) Several stationary horizontal pips appear in the pattern if the ratio of the PRF to the sweep frequency is a whole number. For example, if it is exactly four times as great, four stationary traces are formed. In this case, the PRF is found by multiplying the number of stationary horizontal pips by the indicated frequency of the oscillator.

An excellent indication of the accuracy of the radar whose signal is intercepted is its use or lack of lobe switching. This is readily detected by observing its pulse pattern with the analyzer set for PD operation. If the pulse waveform is double, triple, or quadruple, with all pulses having the same base and shape, the indication is that lobe switching is being used. If pulses merge into a single outline, the radar has detected the search plane and is tracking it.

ECM Direction Finders

One of the essential things to learn about any radar or radio station operated by the enemy is its exact location. In search intercept flights this information can be obtained by the use of airborne ECM direction finders which have been developed for this particular purpose. The enemy transmitter reveals its location as long as it is sending out radio waves; but the problem of analyzing the emissions is complicated by the fact that the enemy may choose either vertical or horizontal polarization. Consequently, the direction finder must be capable of receiving either type of transmission. In the AN/APA–24, a direction finder which oper-

ates between 100 and 450 megacycles, two antenna systems are used. One is a 4-element Adcock array for reception of vertically-polarized signals; the other is a horizontal dipole used for reception of horizontally-polarized waves.

In ECM direction finders designed for higher frequencies, typical equipments employ continuously rotating antennas which are highly directional. Signals received are displayed on a cathode-ray indicator on which is presented a polar diagram of reception obtained throughout 360 degrees of rotation of the antenna. The pattern contains a major lobe which indicates the relative bearing of the station whose signals are displayed.

To locate a particular transmitter, the operator makes several readings of its relative bearing by means of the direction finder display. Each of these readings is called a "cut." With each cut, he records the time and the compass heading of the plane. This information is given to the navigator, who can determine, from the track of the flight, the exact location of the aircraft corresponding to each direction-finding cut. The track of the plane is then drawn on a chart and along it is marked the position at which each cut was made. Through each position a line is drawn, which makes an angle with the track equal to the recorded value of the relative bearing for that point. The intersection of the lines on the chart indicates the position of the enemy transmitter.

The direction finder display can also be used to learn the types of modulation of intercepted signals and to estimate pulse widths and repetition rates, and to determine the polarization of radar antennas.

INDICATOR PATTERNS.—The cathode-ray screen of ECM direction finders employing visual displays shows the operator a polar graph in which the strength of received signals is plotted against relative bearing. To form the patterns, signals are received by the rotating antennas which are synchronized with the sweep of the cathode-ray beam in the indicator tube. Signals are received from a very small sector at any one time and are amplified and detected in the search receiver. Video pulses from the receiver are applied to the

direction finder for further amplification and when applied to the indicator tube produce patterns similar to those shown in figure 10–9. With each video pulse the electron beam in the C–R tube is deflected outward from the center of the screen so that the length of the trace indicates the relative signal strength. The angular direction of each trace line represents the direction in which the antenna is pointing when the corresponding signal is received. The bearing indicated is relative to the axis of the plane with the top of the indicator screen representing the direction ahead of the aircraft.

To read the relative bearing of a station when its signal is displayed, the operator uses a movable mask on which is inscribed an arrow and which is fitted over the indicator screen. He rotates the mask until the arrow bisects the major lobe of the pattern and then reads the relative bearing on a graduated scale surrounding the face of the indicator tube.

The pattern shown in (A) of figure 10–9 results from the signals of a search radar located dead ahead of the aircraft. The PRF is a comparatively low value as indicated by the wide spacing of the traces. Bright tips appear at the trace ends which are characteristic of pulse-modulated waves such as are emitted by almost all radar transmitters. In (B) of the figure the indicator pattern is that resulting from simultaneous reception of two radars on different bearings.

In (C) of figure 10–9, the pulses are grouped in sets of different length, indicating a lobe-switching radar, possibly a fire control system. The pattern varies with the location of the search plane relative to the direction of the radar lobes. When the pulse groups form a smooth pattern with all traces of equal length, the indication is that the plane is being bracketed by the switching lobes of the radar and that the guns controlled by it are probably trained on the observer.

A signal from a communications transmitter employing voice modulation is shown in (D) of the figure. Communication signals are easily identified by the fact that they do

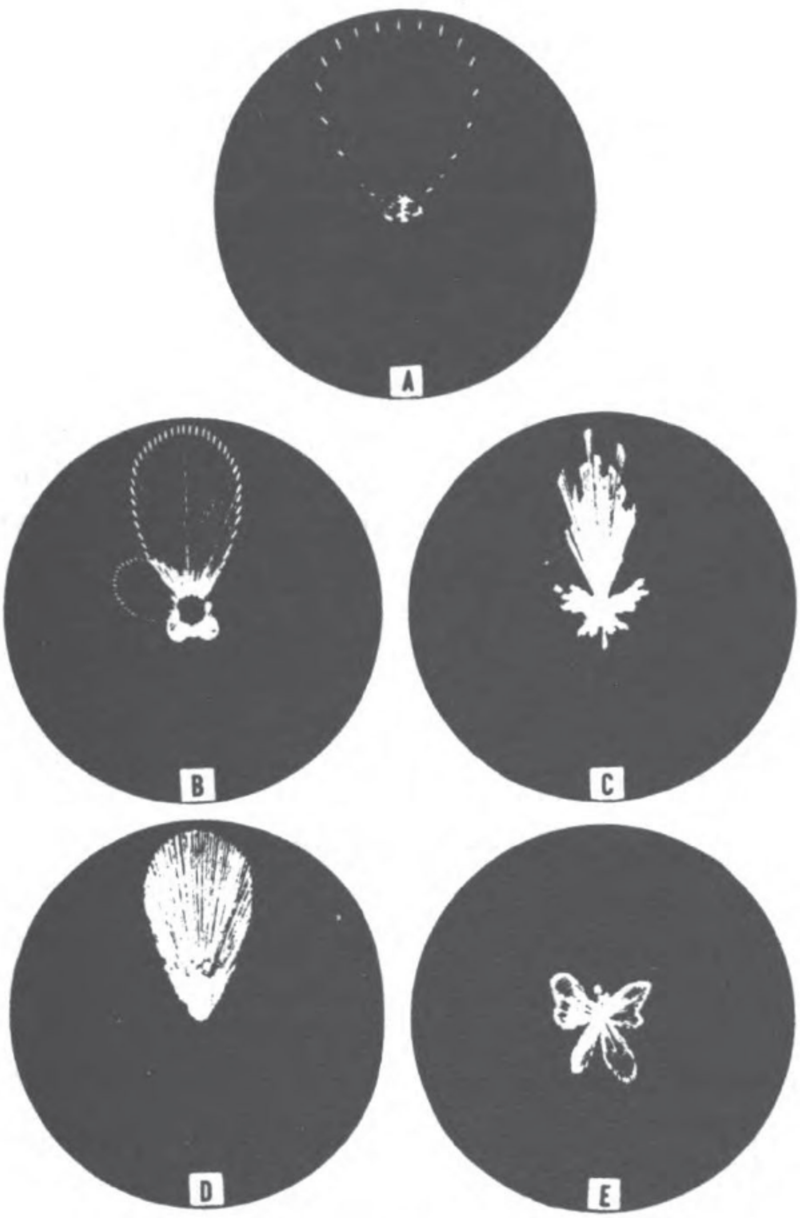


Figure 10–9.—Direction finder patterns.

not produce bright tips on the trace lines and the pattern has a fuzzy appearance. The pattern shown in (E) does not display a marked major lobe and indicates that the polarization of the direction finder antenna is different from that of the polarization of the received waves.

In radar patterns, the lengths of the bright tips on the trace lines provide a means of estimating the pulse width. With the unit whose display patterns are illustrated in figure 10–9, the ratio of the bright length to the total trace

length expressed in percentage is approximately equal to the pulse width in microseconds. For example, if the bright tip is about 5 percent of the trace length, the pulse width is approximately 5 microseconds. The pulse repetition rate of the radar can be estimated roughly by the amount of spacing between the trace lines; however, the spacing is governed to some extent by the rate of rotation of the receiving antennas as well as by the PRF of the signals.

An example of ECM direction-finding equipment which provides the type of display illustrated in figure 10–9 is the AN/APA–17. This direction finder consists of five major components: an antenna assembly, an antenna drive unit, a d-c injector box, a rectifier unit, and an indicator-amplifier containing the cathode-ray tube and the operator's controls. The block diagram of this equipment is shown in figure 10–10.

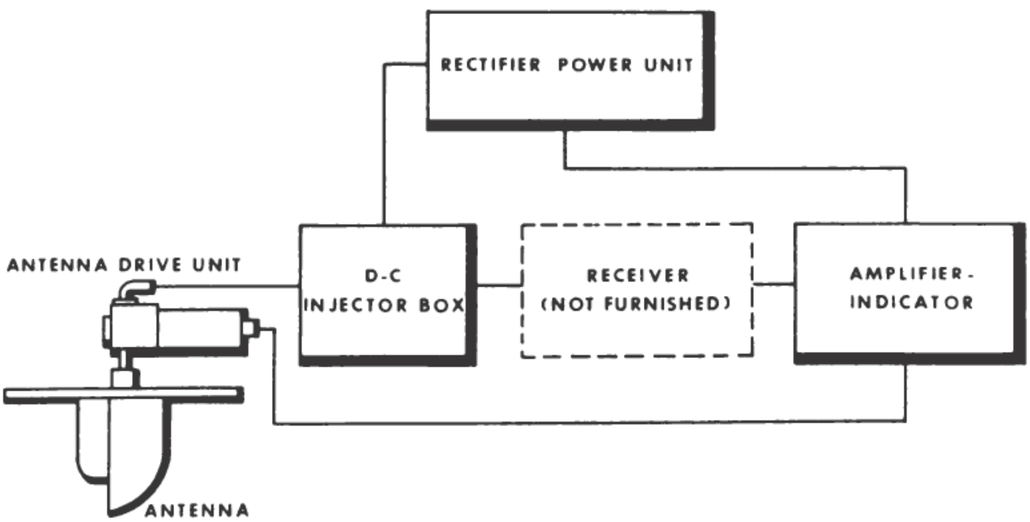


Figure 10–10.—Block diagram of the AN/APA–17 direction finder.

The antenna assembly contains two separate elements, one a horizontal dipole antenna for reception of horizontally-polarized waves, and the other a vertical receiving antenna for reception of vertically-polarized signals. The antennas are mounted on a circular metal disk, and separating them is a metal reflector which causes each element to possess highly directional reception characteristics. The operator chooses one of the antennas by setting a switch located on the panel of the indicator-amplifier unit.

The antenna drive unit provides the means for rotating and controlling the antenna assembly. The receiving antennas are rotated through a gear train driven by a 27-volt, d-c motor which also drives a selsyn generator. The rate of antenna rotation can be varied by the operator from 0 to about 120 r. p. m. by use of a dial on the control panel. The selsyn generator drives another selsyn which serves to control the rotors of a scanning capacitor in the indicator-amplifier so that a relation is established between the position of the antenna and the direction of the signal deflection on the cathode-ray tube screen.

The d-c injector box serves to introduce direct current into the center conductor of the r-f transmission line which connects the direction finder antenna to the search receiver. The direct current is used to operate the antenna-selector relay and is isolated from the r-f circuits by means of filters.

In addition to the cathode-ray tube and various controls, the amplifier-indicator unit contains a series of four video amplifiers which accept the output of the search receiver, amplify it, and apply the result to the indicator tube. A portion of the video signal is fed to the grid of a beam-modulator tube which supplies positive unblanking pulses to the control grid of the cathode-ray tube. The electron beam in the C–R tube is adjusted to cutoff by means of an intensity control so that no trace appears on the screen when signals are not received. The application of signal voltage causes the beam-modulator to supply a positive unblanking voltage to the grid of the indicator tube so that the trace then becomes visible.

The video signals produced at the output of the video amplifiers are capacitively coupled to the deflection plates of the cathode-ray tube through a double-section scanning capacitor. This capacitor, which supplies the beam deflecting voltages required for producing the polar diagram on the screen, is illustrated in simplified form in figure 10–11.

The signals to be displayed are applied to the rotors of the capacitor. The two rotor plates are mounted on a single shaft at an angle of 90 degrees and rotate in synchronism

with the antenna. The rotors are driven by a selsyn receiver which is actuated by a selsyn generator in the antenna assembly. Each of the rotors is capacitively coupled with a pair of stator plates; the stators are connected to the vertical and horizontal deflection plates of the cathode-ray tube. Since the rotating plates are driven in step with the antenna, the signals they couple to the stators and hence to the deflection plates result in visible traces on the screen which correspond in direction to the direction in which the antenna is pointing.

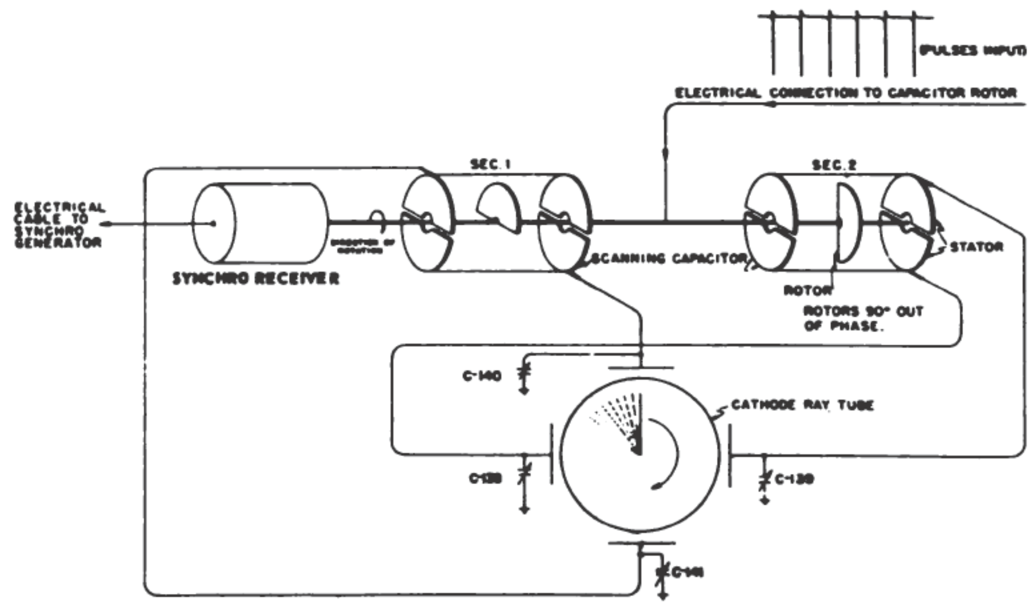


Figure 10–11.—Scanning capacitor.

When the signal voltage coupled to the rotors of the scanning capacitor is either a sine wave or a pulse of considerable duration, the spot on the screen would be deflected in both directions from the center producing a pair of partially overlapping patterns if it were not for the action of four d-c restorer diodes. The plate of each diode is connected to one of the deflection plates of the indicator tube. Each d-c restorer conducts only when the deflection plate to which it is attached is driven positive so that the positive half of any applied signal is effectively short circuited. As a result, only negative-going voltages result in movement of

the electron beam when signals are applied to the deflection plates.

As illustrated in figure 10–11, the negative portion of the signal causes a movement of the beam outward toward the edge of the screen. In the figure, the rotor of section 1 is coupled to the lower of the two vertical deflection plates, producing a negative voltage there which repels the beam and deflects it upward. In section 2, the position of the rotor is such that equal amounts of negative voltage are coupled to both horizontal deflection plates so that no horizontal beam motion results since the repelling forces are equal and opposite. The beam deflection which results when voltages are applied which causes simultaneous horizontal and vertical deflection depends on the vector sum of the two components.

The trimmer capacitors shown in figure 10–11 are used to balance the capacitances of the stator plates to ground.

ACTIVE ECM EQUIPMENT

Active electronic countermeasures are actions taken against the enemy's electronic devices which he can detect and which reduce his effective use of them. These actions consist of jamming, of deception, or a combination of both. The equipments used are of two general types: electronic and nonelectronic. The electronic type includes JAMMING TRANSMITTERS and PULSE-REPEATING UNITS. The jamming transmitter is used to override and interfere with reception of communication, navigation, or radar signals. Pulse-repeating devices are used for deception and are similar to radar beacons. They receive radar signals and respond with pulses which give the enemy false information concerning bearing or range.

Nonelectronic devices are reflecting materials which act as false and confusing targets for enemy radar. They produce echoes by receiving and reradiating the radar waves so that signals are returned to the radar receiver which resemble those from aircraft. Nonelectronic equipments include short strips of metallic foil called WINDOW; longer metallic strips

called ROPE, and CORNER REFLECTORS, which simulate targets much larger than the device itself.

JAMMING TRANSMITTERS.—Electronic jammers are tunable radio transmitters used for producing interference. The jammer radiates a carrier wave modulated with audio voltage suitable for drowning out reception or overloading enemy receivers. One of the most effective kinds of modulation for this purpose is random noise similar to the background disturbances heard in sensitive radio receivers when no station is being received. Noise makes a very desirable jamming signal since it distributes energy over a wide range of frequencies and cannot be filtered without loss of the desired signals. It is also difficult to recognize as man-made interference because of its similarity to atmospheric static impulses. A second type of jamming modulation is caused by sweeping the carrier over a wide range of frequencies at an audio rate. This produces a noise in the receiver much like that of an aircraft engine. Another type consists of a repetition of several audio tones, three to five in number. which give rise to a wailing sound when received.

When operated against radar receivers, the ECM jammer works at a distinct advantage since the echoes returned from most targets are very weak, and the jamming signal usually competes only with low-level radar signals. Hence, an output power in the order of tens of watts can effectively overcome radar pulses originally emitted at a peak power in the order of kilowatts. As a result, low-powered transmitters can jam enemy radar reception at far greater ranges than the maximum effective range of the radar. However, it is necessary that the jamming signal be radiated continuously, so that the output of the ECM transmitter is often as great as the average power of the radar it can successfully jam.

ECM transmitters are used in one of two ways, called SPOT JAMMING and BARRAGE JAMMING. In the first of these, the operator tunes the jammer to the exact frequency of the receiver to be victimized by first tuning in the enemy signal with a search receiver. He then adjusts the output of the transmitter until the two signals coincide in frequency.

Tuning for spot jamming is usually done in flight. Barrage jamming is accomplished by using a number of transmitters as in a formation of planes with each plane carrying at least one jamming transmitter. The units are pretuned to frequencies which differ by about 3 megacycles, a typical value of the bandwidth of an ECM transmitter, and when all are turned on a wide range of frequencies is completely covered.

An example of an airborne jamming transmitter is the AN/APT–5A, which is shown in block diagram form in figure 10–12.

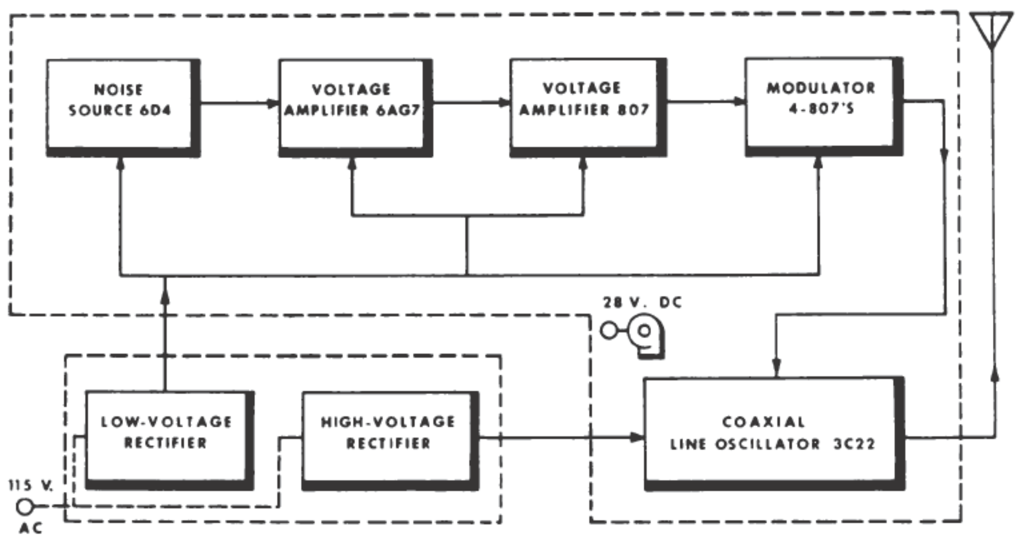


Figure 10–12.—ECM jamming transmitter.

The source of r-f output power is a resonant cavity oscillator circuit constructed around a type 3C22 tube. The tuning circuits are composed of adjustable coaxial lines. Two plungers slide in the lines to vary the length of the active portions which form the resonant cavities. The plungers may be adjusted to positions which provide fundamental mode oscillation, with the active portion of the lines equal to one-quarter wavelength; or for third harmonic operation, with the line lengths equal to three quarter-waves. Operation below 900 megacycles is with the first, or fundamental mode, while the third harmonic mode is employed for frequencies greater than 900 mc.

The modulation used is random noise which is derived

from a 6D4 gas tube. The electron motion in this tube sets up numerous noise impulses which consist of random frequencies distributed over a range of about 3 megacycles. The motions of electrons in the gas tube are influenced by the field provided by a permalloy magnet. The effect of the magnetic field is to make the output level of the noise source nearly equal in value throughout a wide frequency range.

The noise generator is followed by a pentode voltage amplifier which is followed by a type 807 tube used as a driver. Peaking coils are included in the voltage amplifier circuit to maintain a flat frequency response over the range of noise frequencies present.

The driver is followed by four 807 tubes connected in parallel which serve as a modulator. The modulator output is impressed on the plate of the oscillator tube by means of a modulation choke coil in series with the oscillator plate lead.

An external current meter can be attached to a meter connection on the control panel of the transmitter. A switch is provided so that current can be measured in the cathode of the modulator and in the grid and plate circuits of the oscillator.

ANTIJAMMING CIRCUITS.—An ECM development relating to active jamming is the antijamming circuit often installed in receivers, particularly those in radars. The antijamming device is designed to decrease the effectiveness of enemy jamming and hence is called a "counter-countermeasure." These circuits have two uses: they prevent interfering signals from overloading the receiver, and tend to separate the desired signals from the jamming signals. Typical antijamming circuits are simple inductance-resistance filters of the high-pass type. The effect of the circuit, which is usually associated with the video detector section in the receiver, is to pass the high frequencies present in the signal and suppress low-frequency components. As a result, the leading edges of pulses are accepted by the circuits following the filter and large blocks of jamming voltage are excluded from the video amplifier circuits.

Nonelectronic Jamming

WINDOW and ROPE are code names for strips of aluminum foil used for nonelectronic jamming. The strips act as reflectors, and when released from aircraft, they return echoes to enemy radar receivers. Window (also called CHAFF) is tuned material. The strips of foil are cut to one-half wavelength of the radar signal to be reflected, and each strip acts as a resonant dipole antenna which intercepts and reradiates energy. The dipoles are packaged in cardboard folders which are either dropped manually or released by automatic window dispensing devices. Each package contains foil cut for a certain frequency so that a folder may contain from 50 to over 200,000 dipoles, depending on the wavelength of the system for which it is prepared. Typical bundles contain several thousand strips, and weigh less than two ounces. When the package is released it opens so that the dipoles scatter into the air and begin falling at the rate of about 400 feet per minute.

Skilled radar operators can distinguish between aircraft pips and a single window echo; and for this reason, window is seldom dropped in isolated packages. Usually, a lead plane lays down a path consisting of many packages spaced at intervals of one thousand feet or less. The planes which follow in the formation fly through the resulting clouds of reflectors, and enemy operators find it difficult to separate the single pip of an airplane from the mass of window echoes. Thus, the following planes are protected from radar controlled antiaircraft fire and concealed from air search radars. On the radarscope, the dispensing plane appears as a pip which divides into two parts. The pulse representing the aircraft moves across the screen while additional echoes appear behind it and remain stationary. As the dipoles disperse in the air, the stationary pip grows into a shapeless mass in which the following aircraft are practically invisible. Aircraft must be inside the cloud of reflectors to be hidden; and those behind but not within the cloud can be detected by radar waves which pass through the strips.

Window is often used in conjunction with electronic

jamming transmitters to protect a formation of aircraft from radar controlled gunfire.

Rope is similar to window in that it is a confusion reflector, but it differs from it in length and also in the fact that it is untuned. Strips of rope are aluminum ribbons about 400 feet in length and about one-half inch in width. The ribbons are used as nonresonant reflectors for jamming low-frequency radars and are also employed in regions where the enemy operates many units which differ considerably in frequency. The rope material is dispensed in the form of a roll, one end of which is attached either to a small paper parachute or to a square of cardboard. The rolls equipped with parachutes assume a vertical position while falling and reflect waves that are vertically polarized. Those attached to cardboard squares unwind and float downward in a horizontal position, thereby reflecting horizontally-polarized radar pulses.

QUIZ

1. The objective of electronic countermeasures is
   a. for each weapon used by the enemy, to develop a counterweapon
   b. to make the use of radar ineffective to the enemy
   c. to make the use of guided missiles unprofitable
   d. to obstruct the enemy's profitable employment of the electromagnetic spectrum
2. Active electronic countermeasures action is
   a. the releasing of metallic foil from aircraft or projectile to produce interference to radar
   b. not directly detected by the enemy
   c. reconnaissance or search operations
   d. evasive tactics taken to avoid detection
3. Electronic countermeasures antennas
   a. respond to a narrow range of frequencies
   b. require sharp tuning
   c. are broadband devices
   d. are not critical in regards to impedance matching

4. A cathode-ray oscilloscope and an audio oscillator are sometimes used to measure repetition frequencies when which of the following units is not available?
   a. Panoramic adapter
   b. Pulse analyzer
   c. Search receiver
   d. Direction finder

5. Which of the following is the starting point from which the other signal characteristics of enemy radar are determined?
   a. Type of modulation used
   b. Exact location of the enemy station
   c. Pulse repetition frequency
   d. Carrier frequency

6. The pulse repetition frequency of enemy radar is of value to determine
   a. maximum range of the unit
   b. minimum range of the unit
   c. a close estimate of maximum power output
   d. the pulse width

7. Types of scan can be distinguished by listening to the intercepted signals. The use of lobe switching with fire control would be identified by a
   a. steady whine
   b. varying tone signal
   c. loud steady tone
   d. chattering sound

8. The polarization of the enemy radar antenna is taken into consideration for
   a. measuring beam width
   b. measuring peak power output
   c. planning methods of jamming
   d. obtaining maximum signal in the receiver

9. Passive electronic countermeasures reconnaissance can be carried out without fear of detection because
   a. they operate in sectors which are not scanned
   b. the receiver detects the enemy radar by one-way transmission
   c. they operate at a very low altitude
   d. to the enemy, the signal reduction is proportional to the square of the distance

10. The AN/APR–4 receiver (fig. 10–1) uses a/an
    a. untuned crystal detector to accept all signals in a wide frequency range
    b. continuously tunable input circuit over the range 38 to 4,000 megacycles
    c. beat frequency oscillator to detect CW emissions
    d. r-f stage over the range 38 to 4,000 megacycles

11. For sector sweep operation of the AN/APR–4 (fig. 10–2)
    a. each tuning unit contains a sweep motor
    b. the antenna is rotated through the sector desired
    c. the sector is swept at a fixed rate
    d. automatic permeability tuning is used

12. In the ECM receiver AN/APR–4 the mixer used is a
    a. diode
    b. triode
    c. pentode
    d. pentagrid converter

13. Butterfly tuners are used
    a. for frequencies above 1,000 megacycles
    b. for circuits which generate a large amount of power
    c. for frequencies up to about 1,000 megacycles
    d. because they have 360-degree rotation

14. Search antennas for ECM are usually
    a. folded dipoles
    b. high-Q, broadband antennas
    c. of a high inductance value
    d. low-Q, broadband antennas

15. The wave trap which has a dial calibrated in frequency enables the operator to
    a. eliminate image reception
    b. determine the frequency of an intercepted signal by means of the dial reading
    c. eliminate spurious frequency response
    d. filter out all but the desired frequency

16. In search operations the panoramic adapter is used principally as a
    a. graph of signal intensity
    b. graph of relative frequency
    c. tuning aid
    d. method to determine the types of modulation

17. The input signal to the panoramic adapter consists of
    a. a modulated 10-megacycle signal
    b. a signal 5 megacycles below the station to which the receiver is tuned
    c. a special sort of local oscillator signal
    d. i-f signals from the ECM search receiver

18. The reactance tube in the panoramic adapter
    a. produces a sawtooth to be applied to the deflection plate of the CRT
    b. has the effect of a shunt coil across the tuning tank of the f-m oscillator
    c. has a plate voltage which lags the grid voltage by 90 degrees
    d. is controlled by the f-m oscillator to make 30 sweeps per second

19. The pattern which appears on the screen of the panoramic adapter has a pip which moves in the opposite direction to the true signal when the receiver dial is rotated. This is accompanied by irregular deflections and flashes along the length of the screen. This pattern is caused by
    a. two signals near enough in frequency to produce an audible beat note
    b. pulse modulation with a repetition rate considerably greater than the rate of sweep of the indicator beam
    c. a frequency-modulated carrier accompanied by periodic noise
    d. image reception accompanied by static bursts of noise

20. The servo sweep system in the pulse analyzer (fig. 10–7)
    a. supplies a sawtooth to the CRT deflection plates
    b. supplies a rectangular pulse to unblank the CRT
    c. furnishes a positive pulse to the grid of the sweep tube
    d. is a free-running multivibrator

21. In measuring PRF on the AN/APA–11 pulse analyzer, 5 stationary horizontal pips appear. The sweep frequency is 100 cycles per second. The PRF of the station is
    a. 100 pulses per second
    b. 250 pulses per second
    c. 500 pulses per second
    d. 20 pulses per second

22. When locating an enemy transmitter with an ECM direction finder,
    a. an Adcock antenna is used for horizontally polarized waves
    b. signals are received from a large area at one time and are amplified and detected in the receiver
    c. the operator uses a movable mask to determine maximum signal strength
    d. the operator records the relative bearing and time for each "cut"

23. One of the most effective kinds of modulation used for jamming purposes is
   a. random noise
   b. audio
   c. repetition of several audio tones, causing wailing
   d. sweeping the carrier over a wide range of frequencies at an audio rate

CHAPTER 11

SAFETY PRECAUTIONS IN ELECTRONIC MAINTENANCE

In the performance of his duties, the Aviation Electronics Technician installs, maintains, and repairs electronic and electrical equipment in which dangerously high voltages are very often employed. He works in and near aircraft and often in very limited spaces. Among the possible hazards of his work are electrical fires and noxious gases, which are sometimes generated by faulty electronic and electrical devices.

Because of these dangers, the technician should regard the formation of safe and intelligent work habits as being equal in importance to the development of his knowledge of electronic equipment. One of his primary objectives should be to become a safety specialist, trained in recognizing and correcting dangerous conditions and in avoiding unsafe acts.

Under the heading "Basic Precepts," the *United States Navy Safety Precautions* (OpNav 34P1) makes the following statement:

> "Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained and vigilance is exercised to eliminate unsafe acts."

This publication then gives the following general safety rules which apply to personnel in all types of activities:

> "Each individual concerned shall strictly observe all safety precautions applicable to his work or duty.

"a. Reporting unsafe conditions. Each individual concerned shall report any unsafe condition, or any equipment or material which he considers to be unsafe.

"b. Warning others. Each individual concerned shall warn others whom he believes to be endangered by known hazards or by failure to observe safety precautions.

"c. Personnel protective equipment. Each individual concerned shall wear or use protective clothing or equipment of the type approved for the safe performauce of his work or duty.

"d. Report of injury or ill health. All personnel shall report to their supervisors any injury or evidence of impaired health occurring in the course of work or duty.

"e. Emergency conditions. In the event of an unforseen hazardous occurrence, each individual concerned is expected to exercise such reasonable caution as is appropriate to the situation."

The safety precautions which apply to the work and duty of Aviation Electronics Technicians include those pertaining to work done in and around aircraft, precautions against electric shock and electric burns, and those which concern the proper use of handtools and small power tools. In addition to these, it is also necessary that the technician know the authorized methods for dealing with fires of electric origin, for treating burns, and for giving artificial respiration to persons suffering from electric shock.

SAFETY PRECAUTIONS

PRECAUTIONS WITH REGARD TO AIRCRAFT.—In addition to all local orders and directives, the following general rules should be observed:

Pay strict attention to all warning signs placed in or around any aircraft or in the hangar.

Do not smoke or bring any type of open flame within 50 feet of any parked aircraft. Remember that vapor from aviation fuel can be ignited in a number of ways—by lighted cigarettes, by static discharges, and by sparks from tools or from electrical and electronic equipment. Radio transmitters installed in aircraft should not be operated during fueling of the aircraft, or within 50 feet of any such fueling operation.

Storage batteries should not be disconnected or removed from their circuits within any aircraft immediately after

flight without first ventilating the container to allow any gas accumulated during charging to escape. An inspection should be made before removal to insure the opening of all switches, to prevent the possibility of a spark being generated at the terminal of the battery when the connection is broken.

During refueling, radar equipment should not be operated within 75 feet of the plane, and no electrical apparatus supplied by outside power (such as droplights and floodlights) should be operated in or near it.

See that combustible materials such as rags and clean waste are stowed in covered metal containers. Used waste and rags should never be discarded near aircraft but should always be put in plainly marked metal receptacles.

In the air the pilot in command of the aircraft is responsible for the safe and orderly conduct of the flight. When the technician wishes to operate radio or radar transmitters or to make any unusual repairs on the equipment, he must always request permission from the pilot before proceeding.

GENERAL SAFETY PRECAUTIONS IN ELECTRONIC MAINTENANCE.—Because of the possibility of injury to personnel, the danger of fire, and possible damage to material, all repair and maintenance work on both electronic and electrical equipment should be done ONLY by duly authorized and assigned persons.

When any electronic equipment is to be overhauled or worked on, the main supply switches or cutout switches in each circuit from which power could possibly be fed should be secured in the open position and tagged. The tag should read, "This circuit was ordered open for repairs and shall not be closed except by direct order of . . ." (usually the person directly in charge of the repairs). After the work has been completed, the tag (or tags) should be removed by THE SAME PERSON.

The covers of fuse boxes and junction boxes should be kept securely closed except when work is being done on them. Safety devices such as interlocks, overload relays, and fuses should never be altered or disconnected except for replacements. Safety or protective devices should never be changed or modified in any way without specific authorization.

Fuses should be removed and replaced only after the circuit has been completely deenergized. When a fuse blows, it should be replaced only with a fuse of the same current rating. When possible, the circuit should be carefully checked before making the replacement, since the burned-out fuse is often the result of circuit fault.

Electric detonators.—Certain types of electric detonators can be fired by the action of radio-frequency energy. All electric detonators, or igniters, and also electrically fired rocket motors and electric ordnance fuzes, should never be exposed or located within five feet of any type of transmitting equipment, including antennas and antenna leads. No danger due to radio-frequency potentials exists, however, with detonators of any type while they are enclosed in covered metal containers.

High-voltage precautions.—Personnel should never work alone near high-voltage equipment. Tools and equipment containing metal parts, such as brushes and brooms, should not be used in any area within four feet of high-voltage circuits or any electric wiring having exposed surfaces. The handles of all metal tools, such as pliers and cutters, should be covered with rubber insulating tape. (The use of plastic or cambric sleeving or of friction tape alone for this purpose is prohibited.)

Before a worker touches a capacitor which is connected to a deenergized circuit, or which is disconnected entirely, he should short-circuit the terminals to make sure that the capacitor is completely discharged. Grounded shorting prods should be permanently attached to work benches where radar equipment and other types of electronic devices are regularly serviced.

Do not work on any type of electrical apparatus with wet hands or while wearing wet clothing, and do not wear loose or flapping clothing. The use of thin-soled shoes with metal plates or hobnails is prohibited. Safety shoes with nonconducting soles should be worn if available. Flammable articles, such as celluloid cap visors, should not be worn.

When working on electronic or electrical apparatus, technicians should first remove all rings, wristwatches, brace-

lets, and similar metal items. Care should be taken that the clothing does not contain exposed zippers, metal buttons, or any type of metal fasterner.

Warning signs and suitable guards should be provided to prevent personnel from coming into accidental contact with high voltages.

Transmitter adjustments should not be made while the equipment is energized unless the adjustments can be accomplished from the front control panel. Similar precautions should be taken with oscilloscope circuits, which employ voltages corresponding to those used in transmitting equipment.

ENERGIZED CIRCUITS.—Insofar as is practicable, repair work on energized circuits should NOT be undertaken. When repairs on operating equipment must be made because of emergency conditions, or when such repairs are considered to be essential, the work should be done only by experienced personnel, and if possible, under the supervision of a communications or electronics officer. Every known safety precaution should be carefully observed. Ample light for good illumination should be provided; and the worker should be insulated from ground with some suitable nonconducting material such as several layers of dry canvas, dry wood, or a rubber mat of approved construction. The worker should, if possible, use only one hand in accomplishing the necessary repairs. Helpers should be stationed near the main switch or the circuit breaker so that the equipment can be deenergized immediately in case of emergency. A man qualified in first aid for electric shock should stand by during the entire period of the repair.

VOLATILE LIQUIDS.—Volatile liquids such as insulating varnish, lacquer, turpentine, and kerosene are dangerous when used near electronic equipment which is operating because of the danger of igniting the fumes by sparks. When these liquids are used in compartments containing nonoperating equipment, be sure that there is sufficient ventilation to avoid an accumulation of fumes and that all fumes are cleared before the equipment is energized.

Alcohol should never be used for cleaning in locations where

a spark is possible. Neither should carbon tetrachloride be employed as a cleaning agent. Unlike alcohol, the use of carbon tetrachloride does not create a fire hazard; but it is dangerous because of the injurious effects of breathing its vapor. The careless use of carbon tetrachloride may result in headache, dizziness, and nausea. If the fumes are breathed in poorly ventilated compartments, the effect may be loss of consciousness or even death. For these reasons, the use of carbon tetrachloride as a solvent or cleaner has been specifically prohibited in Navy maintenance operations. When cleaning electrical or electronic equipments or parts, always use the approved cleaning agent, Dry Cleaning Solvent, Federal Specification P–S–661 (Stock Number G51–C–1326–67).

ELECTRICAL FIRES.—In case of electrical fires, the following steps should be taken:

1. Deenergize the circuit.
2. Call the Fire Department if the fire is in a hangar or a shop.
3. Control or extinguish the fire, using the correct type of fire extinguisher.
4. Report the fire to the appropriate authority.

For combating electrical fires, use a CO_2 (carbon dioxide) fire extinguisher and direct it toward the base of the flame. Carbon tetrachloride should never be used for fire fighting since it changes to phosgene (a war gas) upon contact with hot metal, and even in open air this gas creates a hazardous condition. The application of water to electrical fires is dangerous; and foam-type fire extinguishers should not be used since the foam is electrically conductive.

In case of cable fires in which the inner layers of insulation or insulation covered by armor are burning, the only positive method of preventing the fire from running the length of the cable is to cut the cable and separate the two ends.

PRECAUTIONS IN HANDLING CATHODE-RAY TUBES.—The trend toward the use of large cathode-ray tubes has increased the dangers of implosion, or collapse of the glass tubes as a result of atmospheric pressure. The tubes are not dangerous if properly handled; but if they are struck, scratched, dropped,

or handled carelessly in any way, they can very well become an instrument of severe injury or death. The following precautions should be taken for the protection of personnel:

1. Wear goggles to protect the eyes from flying glass particles which result from implosion due to fracture of the envelope. The goggles should be of the type which provide side and front protection and which have clear lenses that can stand a rigid impact test.
2. Wear suitable gloves to protect the hands.
3. Be sure that no part of the body is directly exposed to possible glass splinters caused by implosion. Also remember that the coating on some tubes is poisonous if absorbed into the blood stream.
4. Care of the tube. Do not expose the tube to possible damage. When the tube is needed, remove it from the packing box with caution, taking care not to strike or scratch the envelope. Insert it into the equipment socket cautiously, using only moderate pressure. Do not jiggle the tube. Use these same precautions when removing the tube from the equipment.

When the tube must be set down, it is important that the face be placed on a clean, soft padding. Do not stand directly in front of the face, for accidental implosion may cause it to be propelled directly forward with a velocity sufficient to cause severe injury.

SELENIUM RECTIFIERS.—When selenium rectifiers burn out, fumes of selenium dioxide are liberated which cause an overpowering stench. The fumes are poisonous and should not be breathed. If a rectifier burns out, deenergize the equipment immediately and ventilate the compartment. Allow the damaged rectifier to cool before attempting any repairs. If possible, move the equipment containing it out of doors. Do not touch or handle the defective rectifier while it is hot since a skin burn might result through which some of the selenium compound could be absorbed.

SAFETY PRECAUTIONS IN USING TOOLS.—As a general precaution, be sure that all tools used conform to Navy standards as to quality and type, and use them only for the purposes for which they were intended. All tools in active use

should be maintained in good repair, and all damaged or nonworking tools should be returned to the toolkeeper.

Use only straight, undamaged, and properly sharpened DRILLS. Tighten the drill securely in the chuck using the key provided and never with wrenches or pliers. It is important that the drill be set straight and true in the chuck. The work should be firmly clamped and, if of metal, a center punch should be used to score the material before the drilling operation is started.

When using a portable power drill, grasp it firmly during the operation to prevent it from bucking or breaking loose, thereby causing injury to yourself or damage to the tool.

Care should be taken in selecting the correct type of PLIERS, SIDE CUTTERS, or DIAGONAL CUTTERS. Pliers or cutters should not be used on nuts or pipe fittings. When cutting short pieces, take care that they do not fly and cause injury. The fingers should not be wrapped around the handle of a tool in such a way that they can be pinched or jammed if the tool slips from the work. The use of extensions on the tool handle to increase leverage is prohibited.

In selecting a SCREWDRIVER for electrical work, be sure that it has a nonconducting handle. The screwdriver should not be used as a substitute for a punch or a chisel, and care should be taken that one is selected of the proper size to fit the screw. The point of the screwdriver should be kept in proper shape with a file or a grinding wheel.

Use WRENCHES only if they are in good condition and are right for the job. Never use a wrench as a hammer and do not put an extension on the handle. An adjustable wrench should be faced so that the movable jaw is located forward in the direction in which the handle is to be turned. When working in a confined space, the worker should take care that the grip he uses will not endanger him.

PORTABLE POWER TOOLS.—All portable power tools should be carefully inspected before being used to see that they are clean, well-oiled, and in a proper state of repair. The switches should operate normally, and the cords should be clean and free of defects. The casings of all electrically driven tools should be grounded. Sparking portable electric

tools should not be used in any place where flammable vapors, gases, liquids, or exposed explosives are present.

Be sure that power cords do not come in contact with sharp objects. The cords should not be allowed to kink, nor be left where they might be run over. They should not be allowed to come in contact with oil, grease, hot surfaces, or chemicals; and when damaged, should be replaced instead of being patched with tape.

RESUSCITATION FROM THE EFFECTS OF ELECTRIC SHOCK

ARTIFICIAL RESPIRATION, the mechanical promotion of breathing, is used to resuscitate persons whose breathing has stopped as a result of electric shock, drowning, asphyxiation from gas, strangling, or the presence of a foreign body in the throat. To revive persons suffering from electrocution resulting in a stoppage of breathing, begin artificial respiration immediately. Send another person for a medical officer or other competent medical aid. If there is any serious bleeding, stop it first, but don't waste time on anything else. Seconds count. The longer you wait to begin, the less are the chances of saving the victim.

The approved method of artificial respiration is the back-pressure, arm-lift technique which is illustrated in figure 11–1.

Place the victim so that he is lying in the face-down, or prone, position. Bend both his elbows and place one of his hands on the other. Turn his face so that it is resting on his hands. Quickly sweep your fingers through his mouth to clear it out and be sure that the throat is open. With the same movement, bring the tongue forward so that it cannot stop the air passage.

Kneel at the victim's head, facing him. Kneel on either knee or both—whichever is most comfortable.

Next, place your hands on his midback, just below the shoulder blades, so that the fingers are spread downward and outward and the thumb-tips almost touching. This position is shown in (A) of figure 11–1.

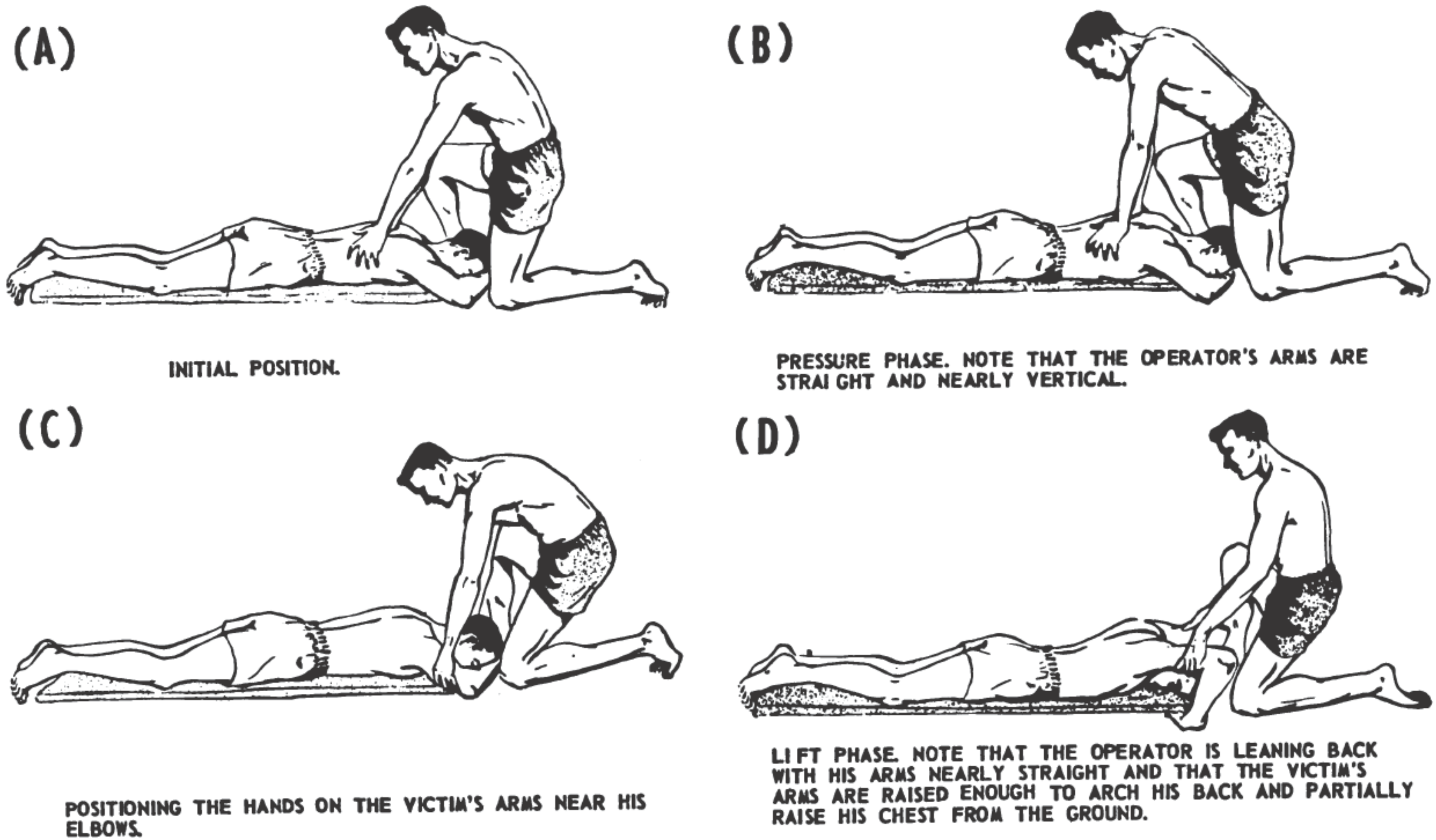


Figure 11–1.—The back-pressure, arm-lift method of artificial respiration.

Rock forward until your arms are approximately vertical, and allow the weight of the upper part of your body to exert a slow, steady pressure on your hands until firm resistance is met. This action compresses the chest and forces air out of the lungs. Keep your elbows straight and your arms almost vertical so that pressure is exerted downward. This phase is illustrated in (B) of figure 11–1.

Be very careful to avoid exerting sudden or excess pressure, and be sure that your hands are not too high up on the victim's back or on his shoulder blades. Release the pressure quickly. "Peel" your hands from his ribs without any extra push. Now rock backward and allow your hands to come to rest on the victim's arms just above his elbows, as shown in (C) of figure 11–1. As you rock backward, draw his arms upward and toward you. Keep your arms nearly straight, as shown in (D) of the figure.

Lift the victim's arms until you feel resistance and tension at the shoulders. The arm lift pulls on the chest muscles, arches the back, and relieves the weight on the chest, thus pulling air into the lungs. Then lower the arms and you have completed one full cycle.

The whole cycle can be chanted to help you keep the rhythm—"Place. . .Swing forward. . .Swing back. . .Lift." Keep this rhythm without stopping once you have begun. The four steps should take about 5 or 6 seconds, allowing 10 or 12 complete cycles a minute. Don't break the rhythm no matter what else is being done, such as:

1. Keeping the victim warm. If someone is there to help you, have him wrap the patient in clothing or a blanket. This can be done between cycles.
2. Loosen his belt or other tight clothing. Your helper can do this too.
3. Moving the victim. This is only to be done if you must, in case of foul weather, fire, or other hazard. After he is breathing on his own, he may be moved, but only in a lying-down position.

When resuscitating a victim of shock by artificial respiration, don't give up too soon. Sometimes it takes several

hours. Be certain that all chance of saving him is gone before you think of stopping.

Keep watching the patient even after he starts to breathe again. If he stops, you must start artificial respiration again immediately. Keep him lying down and warm, even after he comes to. Don't give him anything to drink unless he is fully conscious. If the medical officer has not arrived when the victim regains consciousness, give him some stimulant such as 1 teaspoonful of aromatic spirits of ammonia in a small glass of water, or hot coffee, or hot tea. Do not give the victim alcohol unless you can't get anything else.

TREATMENT OF ELECTRICAL AND THERMAL BURNS

In administering first aid for burns, the objectives are to relieve the pain, to make the patient as comfortable as possible, to prevent infection, and to guard against shock which often accompanies burns of a serious nature.

The greatest pain from a burn is caused by the movement of air over the damaged area. The first step is to cover the burn with some substance which will exclude the air. When the skin is merely reddened and is not broken, cover the burned area with a coating of vaseline, or petroleum jelly. Never put iodine on a burn. Do not apply an antiseptic or a powder; and avoid the use of cotton directly on the burn since it will stick and cause further injury.

If the skin is blistered or if the flesh is cooked and charred, secure the services of a medical officer or a corpsman as soon as possible. If medical aid cannot be obtained in a short period of time, proceed to dress the burned areas as follows:

1. Remove charred materials from the affected area, taking care not to break any blisters which may be present. If clothing is stuck to any part of the surface, do not pull it loose but cut around the cloth and let it stay attached.
2. Apply very thin pieces of sterile vaseline gauze directly over the burned area.
3. Apply cotton wadding, gauze fluffs, or sterile mechan-

ics' waste over the top of the vaseline gauze to give the dressing bulk.

4. Apply elastic bandages to make a snug pressure dressing.
5. Have the patient transferred to a hospital as soon as possible.

QUIZ

1. Combustible materials (oily or greasy rags, dirty waste material, etc.) should be stored in
   a. any convenient out-of-way place
   b. a cardboard box
   c. tool boxes or spare-parts boxes
   d. plainly marked metal receptacles

2. Repair and maintenance work on electronic and electrical equipment should be done by
   a. anyone who can do the work
   b. any technician striker
   c. any technician petty officer
   d. authorized and assigned persons only

3. Interlocks, overload relays, and fuses are safety devices and
   a. should never have checks made on them
   b. should be wired closed
   c. should be wired open
   d. should never be changed or modified without authorization

4. Handles of all tools used around electronic equipment should be insulated with
   a. plastic
   b. cambric sleeving
   c. rubber insulating tape
   d. friction tape

5. Adjustments on an operating transmitter should be made only
   a. from holes through dust covers
   b. from the front control panel
   c. from underneath the equipment
   d. for sixty seconds at a time

350062 O—56——28

6. When working on energized circuits, a helper should be stationed at the
   a. main switch or circuit breaker
   b. nearest doorway or hatch
   c. other side of the equipment
   d. control panel of the equipment

7. If possible, when working on energized circuits, the work should be supervised by the
   a. Electronics Chief
   b. Leading Chief
   c. Executive Officer
   d. Electronics Officer

8. In case of electrical fires, use a
   a. CO_2 fire extinguisher
   b. large quantity of carbon tetrachloride
   c. soda-acid fire extinguisher
   d. foam-type fire extinguisher

9. Which of the following can produce phosgene (a war gas) when in contact with hot metal?
   a. Oxygen
   b. Carbon tetrachloride
   c. Carbon dioxide
   d. Carbon monoxide

10. The first step to take in case of an electrical fire is to
    a. call the Fire Department
    b. report the fire to the OOD
    c. deenergize the circuits concerned
    d. control or extinguish the fire

11. A positive method of preventing internal fires in armored cable from running the entire length of the cable is to
    a. pour water on the cable
    b. cut the cable and separate the two ends
    c. unplug the cable at both ends
    d. use a CO_2 fire extinguisher

12. Which of the following precautions applies when changing cathode-ray tubes?
    a. Wear goggles and gloves
    b. Make the change as rapidly as possible
    c. Exert as much pressure as possible to seat the tube in the socket
    d. Have the Electronics Officer standing by

13. When a selenium rectifier burns out, it liberates fumes of selenium dioxide which are
    a. nonpoisonous
    b. poisonous and should not be breathed
    c. nonpoisonous but cause an overpowering stench
    d. inflammable and of a yellowish color

14. Before starting to drill a hole in metal, score the material with a
    a. center punch
    b. screwdriver
    c. claw hammer
    d. file

15. When using side cutters, diagonal cutters, or pliers, the use of extensions on the handles to increase leverage is
    a. permitted if needed
    b. prohibited
    c. permitted in some cases
    d. highly recommended

16. When selecting a screwdriver for use, the most important consideration is the
    a. length of blade
    b. diameter of the handle
    c. size of the screw-slot
    d. screw material

17. When using an electric portable tool, be certain that
    a. the casing is grounded
    b. a manual tool will not work as well
    c. you have the Electronics Officer's permission to use the tool
    d. you are in an enclosed room

18. When using a screwdriver on electrical work,
    a. use plastic to insulate the handle
    b. be sure that the handle is nonconducting
    c. it may be used as a punch
    d. use a smaller than normal size screwdriver

19. The approved method of artificial respiration is the
    a. prone method
    b. back-pressure, arm-lift method
    c. sixteen count method.
    d. "over and under" method

20. In the approved method of artificial respiration, the hands are removed from the victim's back in a manner best described as
    a. lifting
    b. peeling
    c. casting
    d. dropping

21. A person giving artificial respiration in the approved method kneels on either or both knees at the victim's
    a. left shoulder
    b. right shoulder
    c. head
    d. waist

22. In treating burns, if the flesh is blistered or cooked and charred, dress the wound as follows:
    a. Pull all clothing away and cover wound with powdered antiseptic
    b. Break all blisters and apply iodine
    c. Remove any loose clothing and apply sterile vaseline gauze
    d. Wash wound in warm water and wrap in common cotton gauze

23. After artificial respiration when the victim has fully regained consciousness, give him a stimulant to drink composed of
    a. one teaspoonful of aromatic spirits of ammonia in a small glass of water
    b. one teaspoonful of baking soda in a small glass of water
    c. a cup of ice-cold tea or coffee
    d. any type of alcoholic liquor and cold milk

24. In giving artificial respiration, during one minute's time you should make approximately
    a. 20 to 24 complete cycles
    b. 10 to 12 complete cycles
    c. 5 to 6 complete cycles
    d. any number of complete cycles suitable to you

APPENDIX I

MAGNETIC AMPLIFIERS

The magnetic amplifier, a rising competitor of the electron tube in power and control applications, is rapidly becoming an important element in naval electronics. Amplifiers of this type have many features which are desirable in military equipment: They provide large amounts of voltage or power gain; they are reliable and of rugged construction; they require no cathode heating power and no high d-c potentials as do electron tubes; and they are relatively simple in operation.

Magnetic amplifiers are devices which control the degree of magnetization in the core of a coil in order to control the flow of current or the application of voltage to a load. Many types of circuits are in use. In its basic form, the magnetic amplifier is often called a SATURABLE REACTOR, and consists of two or more coils wound on a common core made of magnetic material. A d-c control voltage is applied to one of the windings and the resulting current serves to modify the reactance of a second winding by causing magnetic saturation of the common core. The second coil, which is connected in the a-c load circuit, varies the current in accordance with changes made in the control-circuit voltage. In more complex magnetic circuits, dry-disk rectifiers are often employed; and the control signal may be either d-c or a properly phased a-c voltage.

Saturable reactors have been used for many years for various purposes—for controlling electric motors, for regulating the output voltages of generators, and for controlling the operation of theater lighting circuits. But until comparatively recent times magnetic circuits have had little application in aviation electronic systems because of the excessive weight and size and the slowness of response of the available units. With the development of many new and improved magnetic materials, there has been a parallel development of many kinds of magnetic arrangements designed to provide "tubeless amplification," and many of these are now employed in aviation equipment.

To give a few important examples, magnetic amplifiers are very frequently used in conjunction with servomechanisms in airborne radar systems, in IFF, and in fire control equipments. They are also employed in the electrical systems associated with the aircraft: in various types of voltage regulators for a-c generators, in devices such as the P–1 Autopilot, and in auxiliary power supplies such as the NC–5 Mobile Power Unit. In view of their increasing application, an under-

standing of the operation of magnetic amplifiers and their basic advantages and disadvantages has become a necessary part of the Aviation Electronics Technician's technical knowledge.

BASIC OPERATION

The basic action of the saturable reactor, the simplest form of magnetic amplifier, can be illustrated by the circuit shown in figure I-1. A source of alternating voltage is applied to a load resistor through a series coil wound on a ring-shaped core. The core material is a good conductor of magnetic flux lines. The number of turns in the winding and the frequency of the applied voltage are such that the reactance of the series coil is high when no control current is flowing in the d-c control circuit, shown at the left in the drawing.

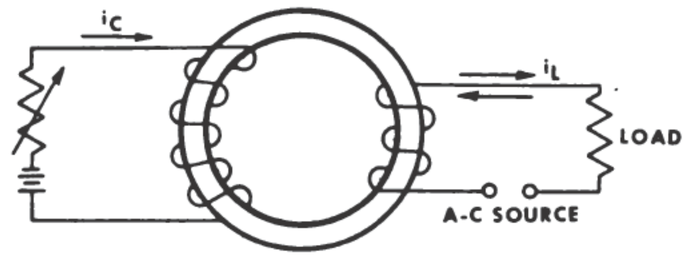


Figure I-1.—Basic saturable reactor.

CIRCUIT ACTION.—The amount of d-c control current is the principal factor determining the amount of magnetic flux in the core, which in turn determines the inductance of the series coil in the load circuit. As the inductance changes, so does the inductive reactance of the series coil and hence the total impedance limiting the load current. The operation of the reactor, then, involves the control of load current by adjusting the d-c level of the control current. The basic relation of the two circuits is as follows: As the d-c control current is increased, the load current increases; and as the d-c control current is decreased, the load current diminishes accordingly. The number of turns in the control winding can be made large so that the effect of the d-c circuit is large; and a comparatively small change in control current results in a large change in load current. As a result, the magnetic circuit is capable of providing amplification.

In a very general sense, the action just described resembles the operation of the grid and plate circuits of a triode amplifier. But in the magnetic circuit, the basic principle of operation is entirely magnetic in nature and is completely independent of thermionic emission. It consists essentially in bringing the core of the series inductance nearer to or farther from the point of magnetic saturation.

MAGNETIC SATURATION.—This section contains a brief discussion of

saturation, the condition of magnetic materials upon which the action of magnetic amplifiers largely depends. The discussion is related to that given in chapter 7 of *Basic Electricity*, NavPers 10086, to which the reader is referred for an explanation of the general principles of magnetism and the magnetic circuit.

As explained in the basic text, when current flows in the windings of a coil, a magnetomotive force is present; and this force plays a part in the magnetic circuit similar to that of voltage in the electric circuit. The amount of magnetomotive force developed depends upon the number of amperes in the magnetizing current and also upon the number of turns in the coil. Hence the quantity can be expressed in ampere-turns. However, in problems involving magnetic quantities, it is often more convenient to express the fundamental magnetizing force by means of the MAGNETIC FIELD INTENSITY, measured in ampere-turns per unit length (or else in OERSTEDS). This quantity is symbolized by the letter H.

The presence of magnetizing force results in the production of magnetic flux lines, which correspond to current in the electric circuit. The number of flux lines produced depends both upon the amount of magnetizing force and the RELUCTANCE of the material. (The reluctance is the magnetic equivalent of resistance in the electric circuit.)

The degree of magnetization in a given material is measured by the number of flux lines. But usually this condition is stated, not in terms of the total number of lines, but rather in terms of the FLUX DENSITY, the number of lines per unit area (square inch of square centimeter). The symbol generally used to represent flux density is the letter B.

Magnetic saturation involves a special relationship between changes in H and the corresponding changes in B. This condition occurs in materials which are good conductors of magnetic flux lines, such as iron, nickel, cobalt, and numerous alloys of these substances. To exhibit the properties of a magnetic material, a sample is employed as the core of a coil, magnetizing ampere-turns are applied, and the resulting values of flux density corresponding to the various amounts of magnetizing force are plotted to make a graph. If the H values (plotted on the X-axis) are systematically increased and decreased, and both positive and negative magnetizing currents are employed, the resulting plot of the B values (Y-axis) is an S-shaped loop called a HYSTERESIS curve.

These curves reveal the presence of saturation in the magnetic material if the magnetizing ampere-turns are made great enough in value. If the core material is initially unmagnetized, the flux density assumes a high value when the magnetizing current is first applied. It makes large increases in value as the magnetizing force is increased. But when a certain value has been reached, the curve becomes almost flat, and further increases in ampere-turns produce negligible increase

in flux density. When this occurs, the material is in a saturated condition.

A decrease and subsequent reversal of the magnetizing current results in a decrease in the flux density followed by a reversal in the direction of the flux lines. If the reversed magnetizing current is then made large enough in value, saturation reoccurs with the flux lines reversed compared with their direction with positive magnetizing current. The saturated condition is somewhat similar to saturation in vacuum tubes, in which further increase in plate voltage results in no further increase in plate current.

EFFECT OF SATURATION ON INDUCTANCE.—In the operation of magnetic amplifiers, and other circuits containing magnetic material, the importance of saturation lies in its effect on the inductance of the coil in which it occurs. In general, the inductance of a solid-core coil is maximum when the core material is in an unsaturated condition. Upon saturation, the inductance decreases, and its value in henries then becomes the same as an air-core coil with an equivalent number of turns. In short, when saturation takes place, the effect is similar to that produced by removal of the magnetic core.

The decrease in inductance with saturation occurs because of the comparative inability of the coil to generate counter-e. m. f. The inductance value in henries is equal to the number of volts induced across the windings when the current flowing through them changes at unit rate. The amount of voltage induced is directly proportional to the rate at which the magnetic flux varies. When the core of the coil is unsaturated, large variations in the flux can occur, giving high values of counter-e. m. f. and hence a high inductance value. In the saturated condition, the flux can make relatively small changes; therefore its rate of variation is low, and the resulting counter-e. m. f. is correspondingly small.

THE HALF-WAVE AMPLIFIER

In the operation of the simple saturable reactor previously described, the load current reverses in direction; and during alternate half-cycles, it produces magnetic flux which tends to cancel the effects of the control winding and to desaturate the core. As a result, a rather large amount of control current would have to be employed and the gain of the circuit would be quite low as a result. A circuit in which the load current is made unidirectional so as to eliminate any undesirable magnetizing effects is shown in (A) of figure I–2. This arrangement is called a half-wave, self-saturating magnetic amplifier.

The load circuit contains a dry-plate rectifier; and since the load current flows in one direction only, it contributes a d-c component to the total magnetizing ampere-turns. The control circuit contains a source of d-c voltage arranged so that the magnetic flux resulting from the control current may either aid or oppose that resulting from the

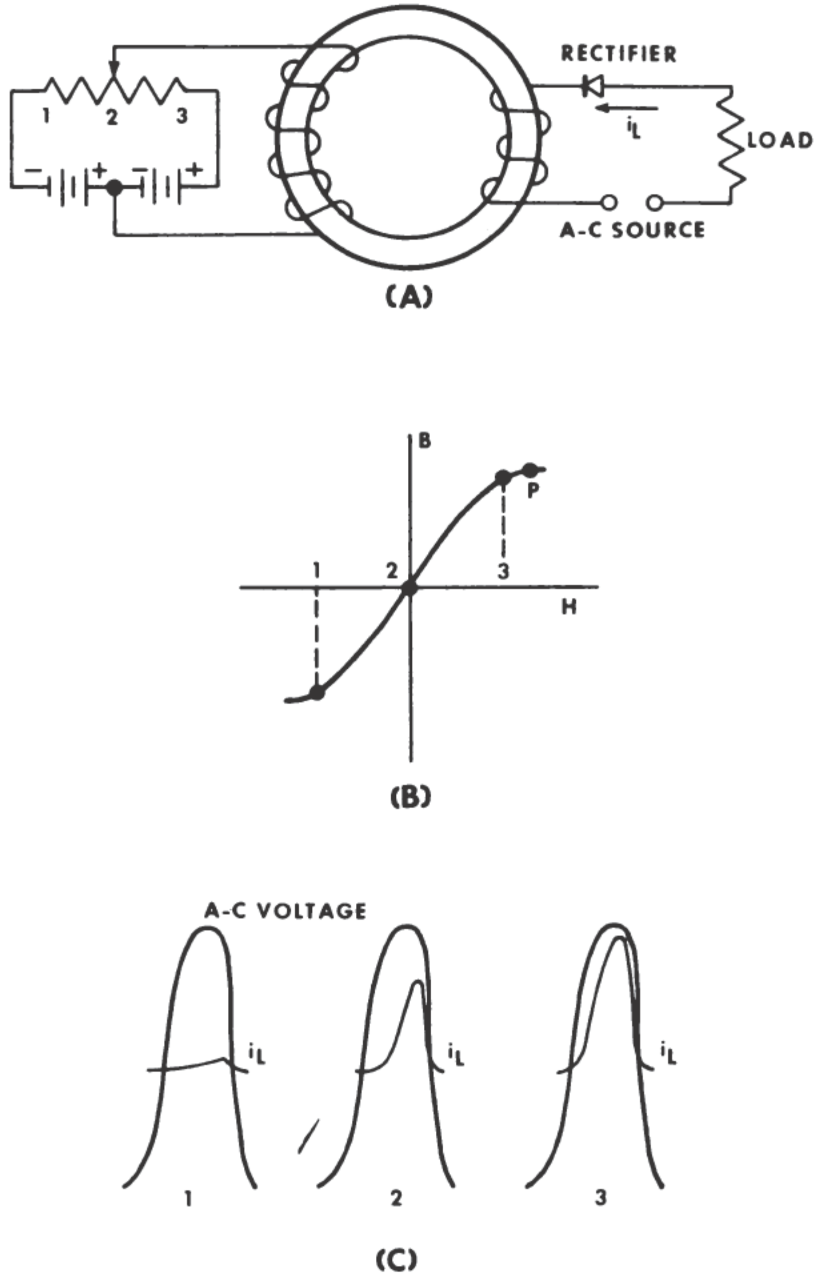


Figure I–2.—(A) Half-wave amplifier; (B) magnetization curve; (C) applied voltage and resulting load current.

load current. When the potentiometer is set at point 1, the control ampere-turns result in flux which is in opposition to the flux associated with the load current. In position 2, no control current flows; and in position 3, the flux produced by the control current is similar in direction to the load current flux.

In (B) of figure I–2, the magnetization curve of the core material is shown with hysteresis effects removed for simplicity. The values of the magnetic field intensity in ampere-turns per inch are represented

by points along the X-axis and flux density along the Y-axis. The values of control current ampere-turns-per-inch which correspond to the numbered positions of the potentiometer are indicated by corresponding numbers on the X-axis. The point P on the curve is the point of saturation.

When no load current is present, the flux density of the core is determined by the amount of control ampere-turns present. Assume that the control potentiometer is set in position 1. When the half-cycle of source voltage, which results in conduction through the rectifier, occurs, the resulting small load current tends to vary the flux along the magnetization curve from left to right, starting at the value corresponding to point 1. Since this point is far from the saturation point, the core remains unsaturated for the duration of the half-cycle of voltage. Consequently, the inductance of the series winding remains high in value, a large counter-e. m. f. is developed, and the value of the load current remains low. The relation of applied voltage and load current for this type of operation is represented in the left-hand drawing in (C) of figure I–2.

In condition 2 of the control potentiometer, no control current flows; and the value of the flux at the start of the conduction half-cycle is nearer the point of saturation. The current flowing in the load circuit increases the ampere-turns in the positive direction as before; but this time saturation is achieved since the initial value of the flux is nearer point P on the curve. At saturation, the value of the load current makes a sudden jump and continues at a high level until the end of the conducting half-cycle of voltage. This condition is illustrated in the center drawing in (C).

In bias condition 3, the initial flux density in the core is quite near saturation so that the inductance is reduced early in the half-cycle and a large value of load current flows as shown in the right-hand drawing in (C).

The operation of the half-wave magnetic amplifier as described above is comparable to the action of a rectifier circuit containing a thyratron tube. When the thyratron grid and plate potentials reach the critical ionizing values, the tube fires and then offers little opposition to current flow for the remainder of the half-cycle of applied plate voltage. Similarly, when the core material of the magnetic amplifier reaches saturation, the opposition offered by the series inductance diminishes. The load current is then limited almost entirely by the load resistance, and conduction is high for the remainder of the half-cycle. Comparatively small changes in the control circuit result in large changes in the load circuit, since control action consists only of determining whether high conduction begins early or late in the cycle. As in thyratron circuits, the controlling voltage of the magnetic circuit may be either d-c or else properly phased a-c signals.

FULL-WAVE MAGNETIC AMPLIFIERS

In most applications of magnetic amplifiers, full-wave operation is desirable. It can be obtained by use of a pair of the simpler half-wave amplifiers similar to the one just described. A typical circuit arrangement is shown in (A) of figure I–3.

The load current is controlled by means of two control windings connected in series. Each amplifier unit contains a rectifier so that load current flows alternately in the two amplifiers. As one conducts, the core of the series coil in the other is being set by the action of the control current. And with each amplifier conducting approximately one half-cycle of load current, the output variations are full-wave in nature.

In (B) of figure I–3, the waveforms are shown which result from zero control current. In this condition, saturation of the magnetic cores of the amplifiers is reached early in each half-cycle, and the resulting output current variations are almost sinusoidal in shape. When a small negative current flows in the control windings, the output resembles the drawing in (C) of the figure, and the average value of the load current is considerably less than that present with zero control current. Thus, as in the half-wave circuit, the output power developed in the load can be varied by controlling the load current. And the range of current values extends from near zero to maximum under the control of a small d-c current which is varied between narrow limits.

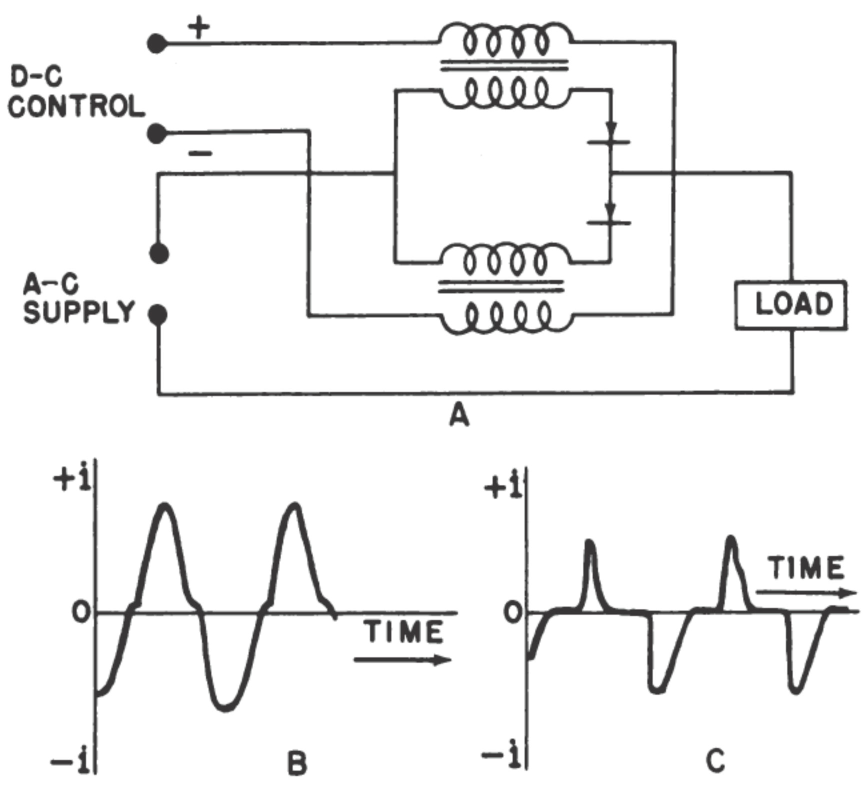


Figure I–3.—Full-wave magnetic amplifier and output waveforms.

D-C OUTPUT AND FEEDBACK

Magnetic amplifiers are very useful for supplying controlled power to loads which require direct current. In these applications, current derived from an a-c source is controlled by the amplifier and is then rectified before application to the load. Consequently, the load current can be made to vary in accordance with the variations of the control circuit as in the previously described amplifiers.

An additional winding may be provided in the amplifier for the purpose of introducing feedback in which variations in the load current introduce corresponding variätions in the control section. A saturable reactor and associated circuits in which both d-c output and series feedback are employed appears in figure I–4.

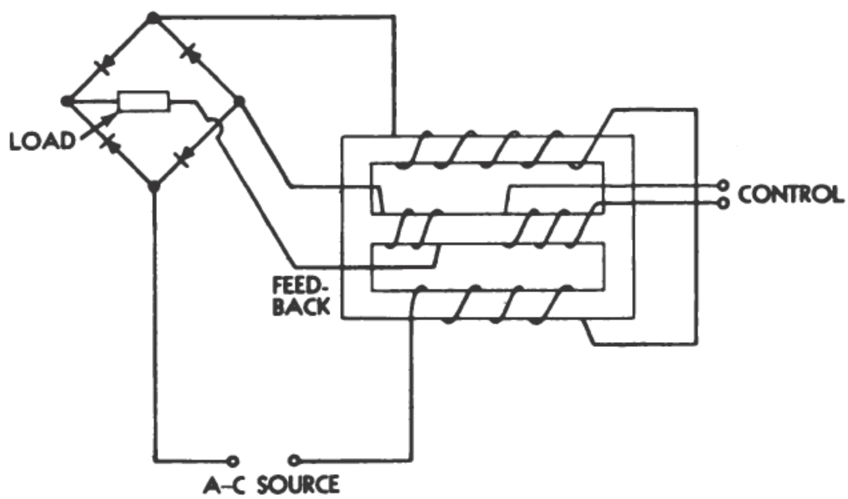


Figure I–4.—Saturable reactor with feedback winding.

In the circuit shown, the a-c source current is rectified in a bridge circuit. The rectifier units usually employed in applications of this type are of the dry-disk, selenium type. These units have a low reverse-current characteristic and are also capable of conducting large amounts of forward current. Selenium units are generally preferred because of their ruggedness, reliability, and exceptionally long life.

The feedback winding on the control leg of the reactor shown in the figure conducts d-c load current and introduces a magnetic component into the control circuit which is proportional to the output current. As in electron-tube amplifiers, the type of feedback action may be either positive or negative, depending upon whether the magnetizing ampere-turns provided by the feedback coil aids or opposes the control ampere-turns. The effect of positive feedback in magnetic amplification is to increase the gain and to introduce a tendency toward instability, just as it does in vacuum-tube circuits. Similarly, negative

magnetic feedback has the general effect of reducing instability and lowering the gain of the stage.

Note that the core of the saturable reactor shown in figure I–4 is a three-legged form. This construction is generally used in reactors of this type and insures that little or no energy is transferred from the a-c windings of the device to the control circuit by means of transformer action. The lines of flux produced in the core by the alternating current are directed around the outer two legs of the core; and cancellation of a-c flux components occurs within the center leg. Hence no induced voltages resulting from a-c variations appear in the control winding.

APPLICATION IN THE P–1 AUTOPILOT SYSTEM

An interesting type of magnetic amplifier, which is somewhat different from the examples discussed above, is used as a motor-controlling device in the P–1 Autopilot. The motors controlled by these amplifiers are included in the servomechanism system of the Autopilot, which is an automatic equipment used to adjust the positions of the rudder, ailerons, and elevator surfaces of the aircraft. The magnetic amplifier and the associated motor in the rudder control channel of the Autopilot system are shown in simplified schematic form in figure I–5.

A separate amplifier unit is provided for each of the two 6V6 tubes shown in the schematic. Each amplifier contains a primary, secondary, and a control winding. The control windings (C) of the two units are connected between the plates of the 6V6 tubes and in series with the secondary of a power transformer. The primary windings (P) are connected in series and are excited from a 400-cycle outside power

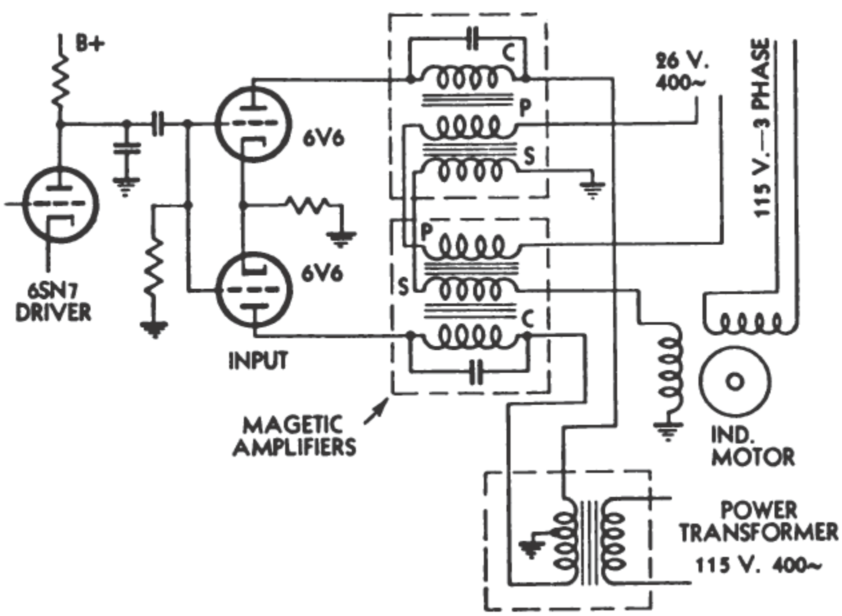


Figure I–5.—Magnetic amplifier used for control of a motor in the P–1 Autopilot.

source. The secondary windings (S) are also in series and are connected to the variable-phase winding of a low-inertia motor in the rudder servo unit.

The plate-voltage variations of the 6V6 tubes are out of phase, being derived from opposite ends of the transformer winding. Hence only one tube can conduct at a time, as determined by the polarity relation between the plate voltage and the a-c signal applied to the grid of the driver tube. When current flows in either plate circuit, the control winding in the associated magnetic amplifier is energized, saturating the core. This condition prevents normal transformer action and limits or cuts off entirely the induced voltage heretofore appearing in the secondary winding (S). The voltage induced in the secondary not under saturation then excites the variable-phase winding of the induction motor.

The secondaries are wound in phase opposition, and the net voltage induced in the variable-phase winding is zero when the input signal to the control tubes is zero. The motor accelerates when the variable-phase winding is energized, and the direction of rotation depends upon which of the tubes supplies the excitation. Reversal of the motor occurs when the phase of the input grid signal reverses with respect to the instantaneous values of the 6V6 plate voltages.

It is interesting to note that the basic principle of operation of the magnetic amplifier in this application is a variation on the basic amplifiers described earlier. In the basic circuits, the load is placed in series with the winding in the amplifier and saturation of the core allows maximum current to flow. In the Autopilot application, the output is taken from the secondary winding of a saturable transformer. Hence, no induced output voltage is present when the core flux reaches a maximum value since in that condition, the flux variations become negligible.

GENERAL CHARACTERISTICS

The magnetic amplifier should not be considered as being a direct substitute for any type of tube or relay now in use in electronic systems. In its present state of development, magnetic amplification is limited in application compared with vacuum-tube circuits and is unsuitable for many of the purposes for which ordinary electronic devices are employed. For example, magnetic amplifiers are not applicable for r-f amplification because of the losses which occur in magnetic core materials at these frequencies. In their present forms, magnetic units are unsuitable for waveshaping circuits. And because of the distortion present in normal operation, they are not well adapted for any sort of amplification which requires that the input waveform be retained with fidelity. Furthermore, magnetic units now available often are more costly than many of their electron-tube counterparts. But regardless of these limitations, magnetic amplifiers have several

built-in advantages which make their use in military equipment very desirable.

Advantages.—In the operation of military electronic equipment, there is a serious problem connected with repair and maintenance. And the features which magnetic amplifiers have to offer in the solution of this problem are ease of maintenance, ruggedness, and long life.

The maintenance required by a magnetic unit without rectifiers is about equal to that required by an ordinary transformer. The units which contain rectifiers require more attention, the maintenance requirements and life expectancy being largely determined by the rectifier components. In these, dry-disk rectifiers of the selenium type are generally employed; and this type of rectifier is rated at 60,000 hours of normal life for ordinary operational demands.

In its ability to withstand shock and overload, the magnetic amplifier is about equivalent to a transformer of similar size. The factor which is most important in giving it an advantage over the vacuum tube in reliability and ruggedness is its independence of thermionic emission. Hence, its operation does not involve fragile filaments. As an example of its trouble-free performance, it was found by examination of the logbook of the German cruiser *Prinz Eugen*, that not one of the various types of magnetic amplifiers used on that vessel for gun stabilizers and in servos required any sort of servicing for a period of 10 years.

Additional features which make magnetic circuits useful in airborne applications are adaptability, safety, high efficiency with high gain, and readiness for instant operation. The amplifiers can be built with specially shaped cores, thereby allowing installation in confined spaces. They can be hermetically sealed for protection against the environment and easily recessed or built into the associated equipment. Since no heater power and no high-voltage d-c power supplies are required, the total equipment has less weight and occupies less space than comparable electronic installations.

In airborne usage, the magnetic circuit has an advantage from the standpoint of safety. The hermetically sealed assemblies can be operated near combustible material with much less danger from sparking or arc-over than with relays and electronic circuits. Also the elimination of high-voltage power supplies removes one major source of hazard for operating and maintenance personnel.

The overall efficiency of the magnetic amplifier is generally higher than that of equivalent electron-tube amplifiers since some of the losses that occur in tubes are avoided. These include the power for cathode heating, the losses by plate dissipation, and those resulting from the use of high-potential B-plus supplies. Magnetic amplification is capable of providing large amounts of gain, both voltage and power. And as in conventional circuits, the magnetic stages can be cascaded to produce any reasonable amount of voltage or power amplification.

Magnetic amplifiers need no warmup time and hence are in a state of continuous readiness. This consideration is very important in equipment such as fire control systems in which the amplifiers and other circuits must be ready for instant use.

DISADVANTAGES.—The principal disadvantage in the operation of magnetic amplifiers results from a time delay which occurs because of the inductive circuits involved. The delay, or lag, is the time interval between the occurrence of a change in control-circuit voltage and the corresponding response made by the load circuit. The amount of time lag present varies with the amount of gain provided by the circuit. It may range in value from an interval equal to one or two cycles of the operating frequency to one equal to several hundred cycles. And since the extent of the delay increases proportionately with the degree of amplification, lag effects are among the limiting factors in the design of high-gain magnetic circuits.

A second important disadvantage results because of the distortion normally present in the output waveforms. These are seldom pure sine waves; and not only is the distortion objectionable in itself, but it is also accompanied by the generation of many harmonic frequencies. The harmonics are very undesirable since some are of such frequency and amplitude that considerable interference with nearby equipment can take place.

For satisfactory operation, the magnetic units must be kept within a range of temperatures extending from about minus 50 degrees to about 100 degrees centigrade. Outside of this range the magnetic properties of the core materials are altered; and also, extremes of temperature have adverse effects on the action of the dry-disk rectifiers which are usually included.

Magnetic amplifiers intended for use in power applications at frequencies in the order of 60 cycles per second are necessarily large in size in order to provide the required inductance. This fact tends to restrict the application in airborne power systems to operation at frequencies such as 400 c. p. s. Also, the input impedance of the typical magnetic circuit is often of incorrect value for matching many types of driving stages, thereby making it necessary to employ impedance-matching networks.

In order to counteract many of these undesirable features, magnetic amplifiers are frequently used in combination with electron-tube circuits. In these combinations, the conventional amplifiers usually provide most of the voltage gain and comprise the earlier stages of the system. The magnetic circuit is employed as the output, or power, stage and delivers the high-level output signals without the use of high-potential d-c sources.

APPENDIX II

AN NOMENCLATURE SYSTEM

The AN letter-number system is used to identify the various kinds and models of electronic apparatus employed by the Army, the Navy, and the Air Force. Separate types of designations are used for complete installations of a particular equipment and for major components of the device. The basic designation for a complete installation is considered first.

An indicator for a complete installation begins with the letters AN. This is followed by a slant bar and a three-letter group. The letters AN are an abbreviation for Army-Navy. The three letters of the second group give the general nature of the installation, the type of equipment, and the purpose of the equipment, respectively. Following the three-letter group is a number which indicates the specific model of the equipment. An example of a basic designation is AN/ARC–2. The letters following the slant bar have the meanings given in the following table.

Table 1.—Set or equipment indicator letters.

Installation	Type of Equipment	Purpose
A—Airborne (installed and operated in aircraft).	A—Invisible light, heat radiation.	A—Auxiliary assemblies (not complete operating sets).
B—Underwater mobile, submarine.	B—Pigeon	B—Bombing.
	C—Carrier	C—Communications (receiving and transmitting).
D—Pilotless carrier	D—Radiac	D—Direction finder.
	E—Nupac (nuclear protection and control).	E—Ejection and/or release.
F—Fixed	F—Photographic	

Table 1.—Set or equipment indicator letters—Continued.

Installation	Type of Equipment	Purpose
G—Ground, general ground use (includes two or more ground installations).	G—Telegraph or teletype.	G—Fire control or searching directing.
	I—Interphone and public address.	H—Recording and/or reproducing (graphic, meteorological, and sound).
	J—Electromechanical (not otherwise covered).	
K—Amphibious	K—Telemetering	
	L—Countermeasures.	
M—Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment).	M—Meteorological	M—Maintenance and test assemblies (including tools).
	N—Sound in air	N—Navigational aid (including altimeters, beacons, compasses, racons, depth sounding approach and landing).
P—Pack or portable (animal or man).	P—Radar	
	Q—Sonar and underwater sound.	Q—Special or combination or purposes.
	R—Radio	R—Receiving, passive detecting.
S—Water surface craft	S—Special types or combination of types, (magnetic, etc.).	S—Detecting and/or range and bearing.

Table 1.—Set or equipment indicator letters—Continued.

Installation	Type of Equipment	Purpose
T—Ground, transportable.	T—Telephone (wire).	T—Transmitting.
U—General utility (includes two or more general installation classes, airborne, shipboard, and ground).		
V—Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, such as tanks).	V—Visual and visible light.	
W—Water; surface and undersurface.	W—Armament (peculiar to armament, not otherwise covered).	W—Control.
	X—Facsimile or television.	X—Identification and recognition.

Using the example AN/ARC–2, the symbols are interpreted as follows: AN means "Army-Navy" and signifies a complete installation. In the three-letter group, the first letter, A, in the first, or "Installation" column, indicates airborne equipment. The second letter, R, is in the "Type of Equipment" column; therefore, it indicates radio equipment. The letter C in the "Purpose" column refers to communication equipment. Hence, the AN/ARC–2 is an airborne radio set used for communication purposes.

The number 2 following the letters of the second group is the model number of the set. If the basic model is modified, the new model is given an additional letter such as A, B, or C, following the model number. For example, AN/ARC–2A is a modified version of the basic AN/ARC–2 model. The next modification is labeled AN/ARC–2B.

When the system just described is applied to subassemblies or major components of the complete installation, the designation is formed by replacing the letters AN with a letter-number group which indicates the type and model of component in question. For example, a control unit used with AN/APS–31 is designated C–289/APS–31. Test equipment used with a particular installation is also designated in the same

general manner. A test set, model 51, used with AN/APG–4 is designated TS–51/APG–4.

The special modification letters X, Y, and Z are used to indicate that the set or equipment has been modified by changes in the primary power requirements as to voltage, phase, or frequency. The letter X indicates the first such change, the letter Y the second, the letter Z the third, and XX the fourth. These letters are used in addition to any other modification letters which apply.

ADDITIONAL DESIGNATORS

In order to identify experimental equipment, a designator is added to parentheses to the basic symbols. An example is AN/ARC–3 (XB–1). The letter X within the parentheses indicates experimental equipment, the second letter identifies the research organization carrying out the experimental development, and the number reveals the particular set developed. When the set has been accepted for general use, the experimental designator is dropped and the basic symbols are used thereafter.

A set designed for training purposes is assigned type numbers as follows:

Equipment designed to train personnel in the use of a specific model is assigned a designator consisting of the basic set symbol followed by a dash, the letter T, and a number. For example: Radio Training Set AN/ARC–6A–T1 is the first training set associated with Radio Set AN/ARC–6A.

Models designed to train personnel in the use of general types of equipment are assigned the basic type indicator followed by a dash, the letter T, and a number. For example: Radio Training Set AN/ARC–T1 is the first training set used for instruction in the general use of airborne radio communication installations.

APPENDIX III

ANSWERS TO QUIZZES

CHAPTER 1

AIRCRAFT ELECTRIC POWER SUPPLY

1. c.	9. b.	17. b.
2. d.	10. a.	18. c.
3. a.	11. b.	19. b.
4. a.	12. a.	20. c.
5. b.	13. c.	21. a.
6. d.	14. c.	22. c.
7. b.	15. c.	23. b.
8. b.	16. d.	24. b.

CHAPTER 2

INTRODUCTION TO AIRBORNE RADAR AND LORAN

1. d.	9. c.	17. a.
2. b.	10. c.	18. b.
3. a.	11. d.	19. a.
4. d.	12. b.	20. d.
5. b.	13. d.	21. d.
6. c.	14. c.	22. a.
7. a.	15. c.	23. c.
8. c.	16. c.	24. a.

CHAPTER 3

AIRCRAFT ELECTRONIC TEST EQUIPMENT

1. c.	6. c.	11. d.
2. a.	7. a.	12. a.
3. d.	8. c.	13. c.
4. c.	9. c.	14. a.
5. a.	10. b.	15. a.

16. d.
17. a.
18. a.
19. b.
20. c.
21. b.
22. a.
23. d.
24. a.

CHAPTER 4

AIRCRAFT ELECTRONIC MAINTENANCE

1. d.
2. c.
3. d.
4. b.
5. b.
6. b.
7. c.
8. d.
9. b.
10. b.
11. a.
12. d.
13. c.
14. b.
15. c.
16. a.
17. d.
18. c.
19. c.
20. b.

CHAPTER 5

MAINTENANCE PUBLICATIONS

1. c.
2. b.
3. d.
4. b.
5. d.
6. b.
7. c.
8. d.
9. b.
10. b.
11. a.
12. c.
13. a.
14. b.
15. d.
16. c.
17. b.
18. a.
19. a.
20. c.
21. a.

CHAPTER 6

THE AN/APS-33 AIRCRAFT RADAR SET

1. b.
2. b.
3. b.
4. d.
5. c.
6. a.
7. c.
8. c.
9. a.
10. b.
11. b.
12. b.
13. c.
14. c.
15. c.
16. b.
17. b.
18. a.
19. a.
20. a.
21. d.
22. b.
23. b.
24. b.

CHAPTER 7

INTRODUCTION TO AIRCRAFT COMMUNICATION EQUIPMENT

1. d.	9. d.	17. a.
2. a.	10. c.	18. c.
3. c.	11. c.	19. b.
4. c.	12. d.	20. c.
5. c.	13. b.	21. b.
6. d.	14. c.	22. d.
7. c.	15. c.	23. c.
8. c.	16. c.	24. b.

CHAPTER 8

AIRCRAFT ELECTRONIC NAVIGATION EQUIPMENT

1. c.	10. a.	19. c.
2. d.	11. a.	20. c.
3. b.	12. d.	21. d.
4. c.	13. b.	22. d.
5. c.	14. c.	23. a.
6. b.	15. b.	24. b.
7. c.	16. a.	25. c.
8. d.	17. b.	
9. b.	18. a.	

CHAPTER 9

INTRODUCTION TO RADAR BOMBING ATTACHMENTS

1. d.	10. d.	19. a.
2. b.	11. a.	20. b.
3. c.	12. d.	21. d.
4. a.	13. d.	22. a.
5. d.	14. b.	23. c.
6. a.	15. c.	24. d.
7. b.	16. a.	25. a.
8. c.	17. d.	
9. c.	18. c.	

CHAPTER 10

AIRBORNE EQUIPMENT FOR ELECTRONIC COUNTERMEASURES

1. d.
2. a.
3. c.
4. b.
5. d.
6. a.
7. d.
8. c.
9. b.
10. c.
11. a.
12. a.
13. c.
14. d.
15. b.
16. c.
17. d.
18. b.
19. d.
20. b.
21. c.
22. d.
23. a.

CHAPTER 11

SAFETY PRECAUTIONS IN ELECTRONIC MAINTENANCE

1. d.
2. d.
3. d.
4. c.
5. b.
6. a.
7. d.
8. a.
9. b.
10. c.
11. b.
12. a.
13. b.
14. a.
15. b.
16. c.
17. a.
18. b.
19. b.
20. b.
21. c.
22. c.
23. a.
24. b.

APPENDIX IV

QUALIFICATIONS FOR ADVANCEMENT IN RATING

AVIATION ELECTRONICS TECHNICIAN (AT)

RATING CODE NO. 6300

General Service Rating

Scope

Aviation electronics technicians test, maintain, and repair aviation electronic equipment: Inspect, clean, lubricate, and make operational tests and adjustments of communications, navigation, search, identification, electronic countermeasures, detection, and relay equipment; remove and reinstall components, assemblies, and subassemblies; calibrate, repair, and make performance measurements; make detailed mechanical, electrical, and electronic casualty analysis; aline search, identification, and relay equipment; make authorized repairs and adjustments to associated test equipment.

Emergency Service Rating

Same as General Service Rating.

Navy Enlisted Classification Codes

For specific Navy enlisted classification codes included within this rating, see Manual of Navy Enlisted Classifications, NAVPERS 15105 (Revised), codes AT–6600 through AT–6699.

Qualifications for Advancement in Rating

Qualifications for advancement in rating	*Applicable rates* AT
100 PRACTICAL FACTORS	
101 OPERATIONAL	
1. Demonstrate under simulated conditions the rescue of a person in contact with an energized electrical circuit, resuscitation of a person unconscious from electrical shock, and treatment for electrical burns	3

Qualifications for advancement in rating	Applicable rates AT
101 OPERATIONAL—Continued	
2. Energize and secure aviation electronic equipment; set operating controls; make operator's adjustments; read and interpret dials, built-in meters, and cathode ray tube presentations	3
102 MAINTENACE AND/OR REPAIR	
1. Select and use hand tools and small portable power tools provided for maintenance and repair of aviation electronic equipment	3
2. Inspect and clean commutators and slipring assemblies; inspect and replace brushes	3
3. Lubricate and clean aviation electronic equipment in accordance with aviation electronic technical and maintenance publications	3
4. Operate the following test equipment:	
a. Ohmmeter	3
b. Ammeter	3
c. Voltmeter	3
d. Megger	3
e. Tube tester	3
f. Echo box	3
g. Frequency meter	3
h. Multimeter	3
5. Make test on aviation electronic equipment for short circuits, grounds, and continuity of interconnecting cables between components, and report results	3
6. Localize aviation electronic equipment casualties in aircraft to removable component	3
7. Make electrical connections and splices, including soldered joints	3
8. Remove and reinstall components of aviation electronic equipment in aircraft; inspect and test for correct installation	3
9. Test and replace electron tubes, fuses, wiring, lamps, and connectors (excluding potting process)	3
10. Draw and interpret schematic diagrams of electrical circuits; read and interpret wiring diagrams of electrical circuits found in aircraft and equipment maintenance publications where applicable to maintenance and repair of aviation electronic equipment	3

Qualifications for advancement in rating	Applicable rates AT
102 MAINTENANCE AND/OR REPAIR—Continued	
11. Locate and identify components of aviation electronic equipment in aircraft by reference to block diagrams and mechanical drawings	3
12. Operate the following test equipment:	
a. Vacuum tube voltmeter	2
b. Oscilloscope	2
c. Spectrum analyzer	2
d. Signal generators	2
e. Frequency meters	2
f. RF wattmeter	2
13. Test aviation electronic equipment for short circuits, grounds, and continuity in electronic circuits; measure electrical quantities, such as voltage, current, power, frequency, and phase angle, and compare with established values; trace signals, using an oscilloscope; determine waveforms and compare with established or required forms	2
14. Localize aviation electronic equipment casualties to detail parts, such as: Resistors, plug-in units, potentiometers, synchros, and tubes within a component, assembly, and subassembly	2
15. Effect alterations or modifications to aviation electronic material in accordance with Aircraft Service Changes and Electronic Material Changes	2
16. Repair and adjust aviation electronic equipment circuitry (excluding the more complex circuits such as SHF, UHF, and pulsed circuits) by replacement or repair of assemblies, subassemblies, or detail parts	2
17. Read and interpret electronic wiring and schematic diagrams, waveform charts, voltage and resistance charts in aviation electronic technical and maintenance publications	2
18. Evaluate test equipment for correct operations: Make authorized repairs and calibrations	1
19. Localize aviation electronic equipment casualties to detail parts within SHF, UHF, and pulsed circuits	1
20. Adjust and aline parts of circuitry in components, assemblies, or subassemblies to conform to allowable limits	1

Qualifications for advancement in rating	*Applicable rates* AT
102 MAINTENANCE AND/OR REPAIR—Continued	
21. Replace, adjust, and/or repair parts of circuitry concerned with SHF, UHF, and pulsed circuits	1
22. Evaluate electrical and electronic tests made on aircraft, aviation electronic equipment, components, assemblies, and subassemblies; reduce data and make corrections; compare values against prescribed performance criteria	C
23. Evaluate repaired, overhauled, or newly installed aviation electronic equipment or components thereof for proper performance	C
24. Screen for feasibility of local repairs: Equipment, components, assemblies, subassemblies, or parts recommended for exchange	C
103 ADMINISTRATIVE AND/OR CLERICAL	
1. Record test data and work accomplished in required work logs; complete check lists	3
2. Prepare reports of equipment failure; prepare shop requisitions for spare parts, tools, and material needed to repair equipment	2
3. Evaluate shop and equipment logs, completed equipment check lists, reports of equipment failure; requisitions for spare parts, tools, and material in repairing equipment	1
4. Take, record, and report inventory of spare parts, tools, test equipment, and materials in shop and shop storeroom	1
5. Train and supervise personnel in maintenance and repair of aviation electronic equipment	1
6. Organize and administer a shop for maintenance and repair of aviation electronic equipment	C
7. Prepare reports covering shop work accomplished, materials used, and status and condition of aviation electronic equipment and test equipment	C
8. Evaluate inventories in terms of shop requirements and prepare requisitions to replenish stock or to obtain new items	C

Qualifications for advancement in rating	*Applicable rates* AT
200 EXAMINATION SUBJECTS	
201 OPERATIONAL	
1. Effects of electrical shock, method of resuscitation of person unconscious from electrical shock, and treatment for electrical burns	3
2. Safety precautions to be observed when working on the line and in a hangar or shop, as set forth in Chapter 3, *U. S. Navy Safety Precautions* (OPNAV 34P1)	3
3. Electrical and electronic safety precautions applicable to aviation personnel as set forth in Chapter 18, *U. S. Navy Safety Precautions* (OPNAV 34P1)	3
202 MAINTENANCE AND/OR REPAIR	
1. Types and purpose of hand tools and small portable tools provided for use in maintenance and repair of aviation electronic equipment	3
2. Function of the following test equipment:	
a. Ohmmeter	3
b. Ammeter	3
c. Voltmeter	3
d. Megger	3
e. Multimeter	3
f. Tube tester	3
g. Echo box	3
h. Frequency meters (portable line maintenance type)	3
3. Operating principles of voltmeter, ammeter, and ohmmeter (but not vacuum tube voltmeter), including:	
a. D'Arsonval meter movement	3
b. Shunts and multipliers	3
c. Use of thermocouples and rectifiers in a-c meters	3
4. Methods and equipment used in electrical test for continuity, grounds, and short circuits	3
5. Soldering materials and methods of soldering used in maintenance and repair of aviation electronic equipment	3
6. Types of information shown and meaning of electrical and electronic symbols used in schematic and block diagrams of aviation electronic equipment	3

Qualifications for advancement in rating	Applicable rates AT
202 MAINTENANCE AND/OR REPAIR—Continued	
7. Units of electrical measurement, including:	
a. Volt	3
b. Ampere	3
c. Ohm	3
d. Watt	3
e. Volt-ampere	3
f. Henry	3
g. Farad	3
h. Cycle	3
i. Ampere-turn	3
j. Prefixing of mega, kilo, milli, and micro	3
8. Meaning of:	
a. Conductors and insulators	3
b. Field intensity	3
c. Flux density	3
d. Permeability	3
e. Hysteresis and eddy currents	3
f. Self and mutual inductance	3
g. Electromagnetic induction	3
h. Power factor	3
i. Reactance	3
j. Impedance	3
k. Capacitance	3
l. Frequency	3
m. Phase	3
n. Time constant	3
9. System of assigning "AN" letter-number combinations as designation for electronic equipment	3
10. RMA color coding systems for capacitors and resistors	3
11. Function of the following in electrical/electronic circuits:	
a. Resistors	3
b. Rheostats and potentiometers	3
c. Solenoids	3
d. Inductors	3
e. Capacitors	3
f. Fuses	3
g. Switches	3
h. Reactors	3
i. Transformers	3
j. Relays	3

Qualifications for advancement in rating	Applicable rates AT
202 MAINTENANCE AND/OR REPAIR—Continued	
12. Operating principles of the following types of electron tubes:	
a. Diode	3
b. Triode	3
c. Tetrode	3
d. Pentode	3
13. Relationship of resistance, inductance, and capacitance in a-c circuits	3
14. Relationship of current, voltage, and impedance in a-c circuits	3
15. Relationship of length and cross-sectional area to resistance of a conductor	3
16. Relationships of resistance, temperature, and current in an electrical conductor	3
17. Calculate current, voltage, and resistance in d-c series and parallel circuits containing not more than four elements	3
18. Construction of motors, generators, and alternators; application of laws of magnetism to electrical rotating machinery	3
19. Effects of meter sensitivity in circuit voltage measurement	3
20. Function of the following test equipment:	
a. Vacuum tube voltmeter	2
b. Oscilloscope	2
c. Spectrum analyzer	2
d. Signal generators	2
e. Frequency meters (shop type)	2
f. RF wattmeter	2
21. Circuit loading effects of test equipment	2
22. Types of electron tubes used in electronic circuits	2
23. Function and operating principles of the following:	
a. D-c power supplies (half-wave, full-wave, and bridgetype rectifiers, voltage doublers, capacitor and choke input filters)	2
b. D-c voltage regulators	2
24. Function and operating principles of the following electronic circuits:	
a. Audio amplifiers	2
b. Video amplifiers	2
c. RF amplifiers	2

202 MAINTENANCE AND/OR REPAIR—Continued	
24. Function and operating principles of the following electronic circuits—Continued	
d. IF amplifiers	2
e. Magnetic amplifiers	2
f. Cathode followers	2
g. Oscillators (Hartley, crystal-controlled, Colpitts, TPTG, and electron-coupled)	2
h. Detectors (diode and crystal)	2
25. Relationship of current, voltage, and impedance in series and parallel resonant circuits at, above and below resonance	2
26. Relationship of reluctance, flux, and magneto motive force in a-c and d-c magnetic circuits	2
27. Calculate current, voltage, phase angle, impedance, and resonance in a-c series and parallel circuits containing not more than four elements	2
28. Operating principles of test equipment authorized for repair and/or calibration	1
29. Methods and equipment used in adjustment and alinement of parts or circuitry in components, assemblies, or subassemblies, to conform to allowable limits	1
30. Operating principles of the following:	
a. Tuned coupling circuits	1
b. Impedance matching	1
c. Phase shifters	1
d. Amplifiers (RF, IF, audio, and video)	1
e. Frequency multipliers	1
f. Cathode followers	1
g. Oscillators (Hartley, crystal-controlled, Colpitts, TPTG, and electron-coupled)	1
h. Detectors (diode and crystal)	1
i. Modulators	1
j. Differentiators	1
k. Intergrators	1
l. Oscillators (blocking and Wein-Bridge)	1
m. Trigger circuits and multivibrators	1
n. Coincidence circuits	1
o. Limiters (noise and pulse)	1

Qualifications for advancement in rating	Applicable rates TA
202 MAINTENANCE AND/OR REPAIR—Continued	
Operating principles of the following—Con.	
p. Clippers	1
q. Discriminators	1
r. AGC and AFC circuits	1
s. Squelch circuits	1
t. Counting circuits	1
u. Sawtooth generators	1
v. Peakers	1
w. Clampers	1
x. Delay lines	1
31. Operating principles of amplitude, frequency, phase, and pulse modulation	1
32. Operating principles of superheterodyne receivers	1
33. Application and operating principles of wire and coaxial transmission lines and wave guides, TR and ATR tubes, klystrons, magnetrons, crystal mixers, and magnetic amplifiers	1
34. Application of low-pass, band-pass, and high-pass filters	1
35. Function and operating principles of gas-filled electron and cathode ray tubes	1
36. Methods of making RF power measurements	1
37. Methods of coupling: Transformer, impedance, capacitance, resistive, and direct	1
38. Functions and applications of servomechanisms and synchros as applied to aviation electronic equipment	1
39. Method of making gain, phase, balancing, and zeroing adjustments to servo loops	1
40. Electrical characteristics of Hertz, Marconi, cone, sleeve, plate, slot, and dipole antennas; operating principles of dish reflectors and associated RF feeds and of parasitic and corner reflectors and directors	C
41. Factors causing and methods of suppressing or eliminating radio noise interference	C
42. Cause and/or effect of induction field, radiation field, sky wave, ground wave, ground reflected wave, ionospheric reflecting layers, skip distances, and maximum usable frequency	C

202 MAINTENANCE AND/OR REPAIR—Continued	
43. Methods of measuring field strength of radio waves	C
44. Effects of various combinations of beam widths, pulse length, pulse repetition frequency, and power output relative to performance and applications of radar equipment	C
45. Effects of environmental conditions upon operation of electronic and electrical equipment, and special maintenance techniques involved in equipments to be operated at extremes of altitude, temperature, and humidity	C
203 ADMINISTRATIVE AND/OR CLERICAL	
1. Types of forms and records used in maintenance and repair of aviation electronic equipment	3
2. Types of information found in aviation electronic technical and maintenance publications	3
3. Types of entries made in electronics portion of Standard Aircraft Inventory Log; types of information recorded in reports of equipment failure	2
4. Types of information found in Electronic Material Bulletins and Changes	2
5. Purpose and type of information contained in Section "R" allowance list of aviation electronic material	2
6. Procedures for obtaining replacement parts, tools, test equipment and materials, within the shop	1
7. Types of information found in Aviation Circular Letters, Aircraft Bulletins, and Aircraft Service Changes	1
8. Application of allowance lists in determining spare parts, tools, and supplies authorized for own activity	1
9. Procedures to be used for obtaining replacement parts, materials, authorized tools, and test equipment for the shop, and for returning defective equipment to supply system for processing to overhaul and repair facilities	C
10. Procedures for survey of accountable material	C
300 PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER	
Aviation Electronics Technicians advance to Warrant Aviation Electronics Technician and/or to Limited Duty Officer, Aviation Electronics.	

INDEX